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Examining Trade Routes through the Thai-Malay Peninsula: A Simulation Analysis

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Examining Trade Routes through the Thai-Malay Peninsula: A Simulation Analysis

An important area for understanding human movement and trade routes during the early historic period in Southeast Asia is the Thai-Malay Peninsula where external records date back 2300 years. Early east-west trade could be routed around the peninsula or reduce sailing time by taking terrestrial shortcuts across the peninsula. However, spatial research, particularly on transpeninsula routes, is insufficient to supplement the gaps between written historical records and excavated archaeological sites. This study aimed to simulate transpeninsula routes across the entire Thai-Malay Peninsula using a digital elevation model (DEM) to eliminate human biases when exploring the actual terrain. The simulation results reveal some intriguing characteristics of potential routes that can be used to divide the Thai-Malay Peninsula into five zones. This zonation is associated with external historical records and archaeological evidence before the twelfth century AD to access the efficacy of different transpeninsula routes. These data are also utilized to propose potential areas of undiscovered archaeological sites within the Thai-Malay Peninsula.

Keywords: Southeast Asia; early historic period; maritime trade; pathfinding

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Introduction and Background

The Thai-Malay Peninsula begins at the southernmost point of the Asian continent in Singapore and Peninsula Malaysia, extending approximately 1,500 kilometers north to southern Myanmar and southern Thailand. This peninsula divides the Andaman Sea and Malacca Strait that are part of the Indian Ocean, from the Gulf of Thailand and South China Sea in the western Pacific (Allen 2017; Jacq-Hergoualc'h 2002, 3–4). The peninsula also consists of two isthmuses, including the Kra Isthmus (the isthmus at the Thai-Myanmar border, around latitude 10.2° N and longitude 98.9° E, less than 60 km across) and the isthmus at the Thai-Malaysian border (around latitude 6.7° N and longitude 100.5° E, approximately 100 km across) henceforth referred to as the Kalah Isthmus, after the old name of the nearby city and mountain range (Figure 1).

Recent archaeological studies in the Thai-Malay Peninsula have discovered bronze and iron tools together with religious and inscribed objects that are presumed to be exotic (Dussubieux et al. 2020; Glover and Jahan 2014; Lankton and Gratuze 2018). However, these objects—which contain short inscriptions using the Brahmi script of the third century BC—are not indicative of such script being widely used regionally. As such, most scholars conventionally refer to this overlapping period from the third century BC to the fifth century AD as the early historic period. This newly defined period was initiated by contact between local groups with foreign merchants and travelers, as seen by the Brahmi script and other contemporaneous artifacts.

Not only did people in Southeast Asia begin to acquire new information and technologies from outsiders, but it is also evident that those from India became aware of the region Asia around the third century BC. Lists of well-known port cities along the maritime trade route such as *Vesuṅga*, *Suvarṇabhūmi*, *Takkola*, and *Suvaṇṇakaṭa*, were

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included in Buddhist texts (Borell 2018; Koad et al. 2023; Wheatley 2017, 181, 269). Around 100 BC, during the Han Dynasty, the Chinese formally established the first political contact with India, in which their envoys had to travel there via a transpeninsula route that took "rather more than ten days" from *Chénlí* on the Gulf of Thailand to *Fūgān* and *Dōulú* on the Andaman Sea (Jacq-Hergoualc'h 2002, 30; Wheatley 2017). At the start of the Christian era, there was also a maritime route between India and China, possibly through the Malacca Strait with a stop at *Pízōng* (likely located in Sumatra) (Jacq-Hergoualc'h 2002, 48, 50; Wheatley 2017, 11–12).

In AD 120, the first Roman envoys arrived in China via the sea route (Borell 2018; Xiong and Lin 2018). The geographical and ethnological information perceived by one of them was recorded and transmitted to the Greek polymath Claudius Ptolemy, who described it in his *Geōgraphikē Hyphēgēsis* (i.e., "Geographical Narrative) around AD 150. In this tome, Southeast Asia is referred to as "India outside the Ganges" and the location of numerous towns and emporia, such as *Bēsynga*, *Chrysē Chersonēsos*, *Chrysē Chōra*, *Takōla* (on the Kra Isthmus), and *Sabana* (on the Kalah Isthmus) were noted (with rough notions of latitude and longitude) (Borell 2018; Koad and Rakmak 2022; Koad et al. 2023; Wheatley 2017, 138). The use of a transpeninsula route across *Chrysē Chersonēsos* (i.e., "the Golden Peninsula", or the Thai-Malay Peninsula) after crossing the Bay of Bengal in the first century AD is also described in this book (Berggren and Jones 2000, 15, 74–76; McCrindle 1927, 22–25). Overall, it is clear that historically, the Thai-Malay Peninsula has been a prominent nexus of interaction and trade beginning by at least 2300 years ago.

At the beginning of the third century AD, most of the Thai-Malay Peninsula was attacked and conquered by the kingdom of Funan (in Cambodia and Vietnam) as attested by several Chinese records (Wheatley 2017, 14–15). However, modern

historians accept that the proper historic period of the Thai-Malay Peninsula began in the sixth century AD. During this time, Buddhist and Hindu statues grew in size compared to earlier historical periods. This observation indicates a significant shift in the religious beliefs of local populations within the Thai-Malay Peninsula who subsequently adopted Indian religions. A century and a half later, Srivijaya, one of the more prominent maritime kingdoms in Southeast Asia, emerged in Sumatra. This kingdom rapidly expanded its territory northward into the Thai-Malay Peninsula until its collapse in the late thirteen century AD when the Singhasari Kingdom in East Java effectively incorporated Srivijaya. Although Srivijaya is an ideal port for circum-peninsula trade and the increasing preference for this option after the early first millennium AD was related to its rise, archaeological evidence indicates that some peninsula routes were still in use during this period.

According to modern archaeologists, the early transfer of cultures and technologies to or from Southeast Asia may have occurred across the Thai-Malay Peninsula during the early historic period (Bellina et al. 2018; Borell et al. 2014). Some of the discovered and excavated archaeological sites in this region indicate that they are production centers that gathered raw materials from nearby territories (or imported them from distant lands) to manufacture goods. Some were trading posts where merchants exchange goods or stopped before continuing their journey. In addition, some of these cities exercised their political and military authority to control and defend their subordinates.

Transpeninsula routes, as part of the maritime trade network, are essential for the formation and growth of states in early historical Thai-Malay Peninsula. However, pinpointing the precise transpeninsula routes utilized by ancient civilizations is challenging. Ancient explorers may not have utilized optimal routes due to surveying

them requires many trial-and-error attempts, which may cost many lives over the centuries. From a practical standpoint, factors such as the control of governments or their relationships with local groups, the competition within or between neighboring governments and various social groups may have limited the use of routes were more efficient. Consequently, some major routes may have at first appeared attractive for trade, but the absence of archaeological evidence suggests that other factors were at play (Jacq-Hergoualc'h 2002, 32, 42).

In modern times, hypothetical ancient transpeninsula routes can be estimated using aerial or satellite imagery (Jacq-Hergoualc'h 2002, 34). However, there is no guarantee that they were used in antiquity, and there may have been routes that are not easily visible. As a result, scholars have tended to rely heavily on archaeological sites that contain evidence for commercial activity to confirm the use of transpeninsula routes. However, traceable surface finds (from accidental discoveries by locals or even illegal excavations) that lack archaeological contexts are garnering more attention. These can often be used for identifying potential routes and their associated archaeological sites (Malakie and Bevan 2017; Pongpanich 2009, 27–32, 36–40).

Furthermore, placing too much emphasis on discovered archaeological evidence without considering other possible datasets can lead to biased interpretations. Other sites may still be undiscovered or even underwater (Jacq-Hergoualc'h 2002, 33; Mangeruga et al. 2014). This dearth of evidence may be obscuring the degrees of interaction between different ancient political entities. For example, current political issues in Myanmar pose a challenge for archaeologists (Jacq-Hergoualc'h 2002, 3, 33).

These issues highlight the difficultly in answering questions related to transpeninsula movements that requires a multidisciplinary effort. These include the use of recent computational approaches that combine modern GIS technologies and

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pathfinding algorithms to reveal optimal routes available in all types of terrain (Lock et al. 2014; Mangeruga et al. 2014; Verhagen et al. 2019). This study explores ancient routes through the Thai-Malay Peninsula by: 1) simulating transpeninsula routes on the digital elevation model (DEM); 2) comparing simulation results with data drawn from historical records and archaeological evidence dating no later than the twelfth century AD; and 3) applying these simulations to the actual terrain.

The goal in simulating these transpeninsula routes is to offer greater insight on the flow of knowledge, cultures, and goods across this region by comparing our results with historical data. This study sheds light on the distribution and relationships between archaeological sites in the Thai-Malay Peninsula and may help pinpoint the locations of ancient towns and emporia that have been recorded in historical accounts from foreign lands. The simulation results can also be used to identify potential links between historical records and archaeological finds in the Thai-Malay Peninsula, thus creating new opportunities for in-depth investigation and comprehension of this culturally rich area.

Simulation Procedures

Spatial Domain

The DEM dataset utilized in our simulation of transpeninsula routes is derived from the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) global digital elevation model (GDEM) version 3 produced by the National Aeronautics and Space Administration (NASA) and Japan's Ministry of Economy, Trade, and Industry (METI) (available at doi:10.5067/ASTER/ASTGTM.003). The horizontal resolution of ASTER GDEM version 3 is one arcsecond or approximately 30 meters at the equator.

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This dataset covering the Thai-Malay Peninsula was downloaded and downsampled to a spatial resolution of 300 m at the equator. It extends from the peninsula's southernmost point to the latitude of 15° N. As a result, waterways with a width of fewer than 300 meters were excluded from the simulation of transpeninsula routes.

When traversing the Thai-Malay Peninsula, it is assumed that individuals would have preferred avoiding hilly terrain. The tropical environment consists primarily of jungle covering the entire mountain with forests and rivers found in the lowlands. As such, in our simulation, we chose a point 300 m above mean sea level as the maximum elevation at which ancient people would traverse the Thai-Malay Peninsula (Figure 1). The simulation examined all possible transpeninsula routes between the eastern (Gulf of Thailand and South China Sea) and western coasts (Andaman Sea and the Strait of Malacca). The eastern coast begins in Samut Prakan, Thailand, to the west of the Chao Phraya River (on Bangkok Bay in the Gulf of Thailand), and the western coast begins at the Tavoy River in Dawei, Myanmar (on the Gulf of Martaban). Both coastlines descend to the southernmost tip of the Thai-Malay Peninsula in Malaysia (Figure 1).

One could argue that the ancient coastline of the Thai-Malay Peninsula differed from the modern coastline and that using current coastlines in the simulation could produce inaccurate results. Recent research indicates that approximately 7000 years ago, during the Holocene climate optimum, the average sea level around the Gulf of Thailand was 3 to 5 m higher than it is today, but did not exceed 5 m (Parham et al. 2014; Sinsakul 2000). The maximum rate of change is also estimated to be approximately –0.7 m per millennium. Moreover, if we assume that sea level in this study is set to 2 m above the current mean sea level, then the estimated interval of time would be approximately 3000 years ago, corresponding well with the proposed period when the inland trade networks between human settlements in Southeast Asia were

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fully established.

As a result, it is safe to assume that 2 m contour lines on the topography is sufficient to define the maximum extent of coastlines less than 3000 years ago. It is also possible to infer that this sea level can be used to represent the coastline approximately 3000 years ago or less and that it should be comparable to that of the present day, such that the difference in simulated walk times is negligible and can be disregarded. Therefore, this study assumes that both the eastern and western coastlines from 1000 BC to the present day are static and can be used to satisfactorily simulate transpeninsula routes during the Thai-Malay Peninsula's early historical periods.

Cost Function

Time-optimized transpeninsula routes from every point along eastern and western coastlines were determined using Tobler's hiking function computed using the DEM of the Thai-Malay Peninsula as the cost function (Goodchild 2020; Magyari-Sáska and Dombay 2012). If one walks along a straight line joining two points over flat terrain (i.e., free from obstacles), Tobler's hiking function gives a typical walk time t in hour given the horizontal distance d and the elevation difference h (both in km) as

$$t(h,d) = \frac{\sqrt{h^2 + d^2}}{6} \exp\left(3.5\left|\frac{h}{d} + 0.05\right|\right). \tag{1}$$

From this function, in the case of flat terrain, the typical walking pace for humans is about 12 min/km distance (t = 11.9125 minutes where d = 1 km and h = 0 m) (Figure 2A). The maximum walk speed of 6 km/hr (i.e., the pace of 10 min/km) is achieved when walking down the inclined terrain with the decreasing elevation rate of 50 m per 1 km of horizontal distance (t = 11.9125 minutes where h/d = −50 m/km or equivalent to the slope of −2.86°) (Figure 2B).

Tobler's hiking function is an enhanced version of the original Naismith's rule (which does not account for the case of a negative slope) and Langmuir's corrections (which accounted for the negative slope but resulted in a discontinuous function) (Goodchild 2020; Magyari-Sáska and Dombay 2012). Note that walking uphill always takes longer than walking downhill, indicating that this cost function is also direction-dependent. Since the spatial domain used in this study is a raster dataset comprised of rectangular cells, there are eight possible directions: four directions to edge-adjacent cells (north, east, south, and west) and four directions to vertex-adjacent cells (northeast, southeast, southwest, and northwest).

Pathfinding Algorithm

Since the nineteenth century AD, numerous pathfinding algorithms have been developed which are still in use today as part of non-machine learning artificial intelligence (Herzog 2014). Although some brute-force algorithms, such as the breadth-first and depth-first search, use more memory and require a longer computation time than others, they are guaranteed to produce the global solution if sufficient memory and time are available (Zarembo and Kodors 2013). On the other hand, the A* search algorithm and its variants are based on the heuristic concept, which optimizes memory and computation time but reduces the precision of the results (i.e., it does not always return the optimal route) (Abd Algfoor et al. 2015).

The Bellman-Ford algorithm and Dijkstra's algorithm (and their variants) are based on the relaxation principle by constructing possible nearby routes adjacent to the current point, then locally optimizing these routes and discarding all visited routes (Abd Algfoor et al. 2015; Herzog 2014; Zarembo and Kodors 2013). This method is repeated until the desired location is reached. These algorithms consume significantly less

memory and processing time than brute-force-based algorithms while still ensuring the global solution that they always yield the optimal results over the entire search domain. The Bellman-Ford algorithm is more versatile than the Dijkstra's algorithm because it can be used to solve problems involving a negative cost function. In the case of positive functions, such as travel distance and time, the latter typically requires less computational time. The Dijkstra's algorithm is, therefore, the optimal pathfinding algorithm for simulating transpeninsula routes.

The simulation can be demonstrated with an example of a hypothetical traveler. Assume that an individual must optimally walk from a starting point on the western coast, that they must clone other bodies from themselves, and that each clone must walk in each direction to all nearby points in the time specified by Tobler's hiking function. If one of them has reached a new location, they must clone other bodies to walk in any direction to the following unvisited locations (Figure 3A). However, they cannot ascend to any point higher than 300 meters above mean sea level, and cannot walk to a point previously visited by another route. Furthermore, if there are no unvisited points surrounding them, their course will be marked as terminated, and they will be unable to continue walking. This process is repeated each time a point is visited until a destination point on the eastern coast is reached (Figure 3B).

For every initial point along the eastern and western coasts, the simulation of a single transpeninsula route is repeated. Finally, all simulated transpeninsula routes were manually analyzed by validating them with historical records and archaeological remains discovered nearby. These computer-optimized routes provide crucial information for the study of territorial dynamics and reveal some possible missing links in the region's trade networks.

Results

The simulation yielded a total of 24,418 transpeninsula routes, consisting of 15,009 routes from the western to eastern coasts and 9,418 routes in the opposite direction (Figure 4-6). Due to the length and narrowness of the Thai-Malay Peninsula, the computer-optimized routes converged on several specific destinations. In this study, all routes leading to the same destination point (or a group of nearby destinations with a maximum distance of 15 kilometers between them) were grouped into a single set, and the route with the shortest walk time was chosen as the primary route for that set. Present-day locations of initial and destination points of main routes and their walk times are given in Table 1-3.

The results of our simulations infer some intriguing aspects of possible transpeninsula routes. If we assume that an individual disembarked at a point on the western coast and began walking in any direction, the quickest route from their starting point would typically terminate at a river mouth or bay on the eastern coast. In addition, if others had landed nearby, they would have discovered that the quickest routes typically converge to a single route and end at the same or a nearby destination (Figure 4-6). If there were substantial bodies of water or steep hills and mountains, the change in direction could occur along these routes to avoid these geological obstacles, resulting in faster convergence.

Each set of converged routes always included a route that was the fastest; this route is known as a secondary route. The convergence of nearby land routes and the concave shoreline of destination points is also encountered by traders who land on the eastern coast and whose final destination is on the western coast. Some forward routes from the western to the eastern coasts coincide with their reverse routes from the eastern

to the western coasts (Figure 4-6; Table 1-3). These routes are henceforth referred to as primary routes.

The Northern Thai-Malay Peninsula (Zone 1)

This region has only two primary routes and no secondary routes (Table 1). The first primary route links the mouth of the Tavoy River near Dawei City, Myanmar, on the Andaman Sea (01W in Table 2) to the mouth of the Bang Tabun River in Phetchaburi, Thailand, on the Gulf of Thailand (01E in Table 3) (Figure 4A and S1A). It penetrates the Tenasserim Mountains and passes through the permanent border crossing station at Phu Namron. This route has a mean estimated walking time of 55.33 hours and a total horizontal distance of 269 km, making it the route with the longest travel time and distance in this study (Table 1).

The second primary route connects the mouth of the Lenya River in Myanmar on the Andaman Sea at 85 km south of the port city of Myeik (02W in Table 2) to the mouth of the Wa Thon River on the Gulf of Thailand (02E in Table 3) for 16 km (Figure 4A and S1B). This route also includes the Mawdaung-Singkhon Pass through the Tenasserim Mountains.

The Kra Isthmus (Zone 2)

There are two primary and five secondary routes in this zone (Table 1). The first primary route across the Kra Isthmus from the mouth of the Lam Liang River in Ranong, Thailand (06W in Table 2, it is a tributary of the Kra Buri River, which flows into the Andaman Sea) to the Thung Kha-Sawi Bay in Chumphon on the Gulf of Thailand (06E in Table 3) (Figure 4B and S2A). This 47 km land route traverses the Thai-Malay Peninsula in the shortest distance, with an estimated mean walking time of

only 9.84 hours (Table 1). However, if the mouth of the Kra Buri River was used as the starting point, the 43 km of sailing distance up the Kra Buri River must be considered.

The second primary route in this zone begins in the Andaman Sea at Son Bay in Ranong (09W in Table 2), passes through the Phato Pass, and then reaches the mouth of the Bang Man River in Chumphon on the Gulf of Thailand (09E in Table 3) (Figure 4B and S2B). Secondary routes in this zone connect the coastlines of the Kawthaung District at the southernmost tip of Myanmar and Ranong in southern Thailand on the Andaman Sea to the coastlines of Prachuap Khiri Khan, Chumphon, and Surat Thani in southern Thailand on the Gulf of Thailand.

The Central Thai-Malay Peninsula (Zone 3)

This zone has two primary routes and three secondary routes (Table 1). The first secondary route begins at Phra Thong Island in Phang Nga on the Andaman Sea (10W in Table 2), crosses the valley currently submerged beneath the Ratchaprapha Reservoir, and continues to the Tha Chang-Phunphin River mouths (10E in Table 3), which flows into Bandon Bay (Figure 5A and S3A). However, this currently submerged transpeninsula route was simulated without using the bathymetry of Ratchaprapha Reservoir because this dataset is not available to the public. One can also return to the Andaman Sea from Bandon Bay via a secondary route that connects the mouths of the Tapi River (11E in Table 3) and the Marui River (11W in Table 2), which flow into Phang Nga Bay (Figure 5A and S3A).

The first primary route in this zone connects the mouths of the Phela-Khlong Thom River in Krabi (12W in Table 2) to the mouth of the Tha Phae River in Nakhon Si Thammarat (12E in Table 3) via the Krarom Pass of the Nakhon Si Thammarat Mountains (Figure 5A and S3B).

The simulation also provides a secondary route from Pak Phanang Bay in Nakhon Si Thammarat (13E in Table 3) to the mouth of the Kalase Yai River in Trang on the Andaman Sea (13W in Table 2). A remaining primary route suggests a connection between the Trang-Palian River mouths on the Andaman Sea coast (14W in Table 2) and the mouth of the Lam Pam River (14E in Table 3), which flows into the Thale Luang (Figure 5A and S4A). Despite its relatively short distance, one must account for additional travel time across the Thale Luang for approximately 20 km to the Sathing Phra Peninsula in Songkhla and then walk for less than 10 km to reach the Gulf of Thailand.

The Kalah Isthmus (Zone 4)

There is only one primary route in this region, but five secondary routes (Table 1). The only primary route begins at the Baraket-Thung Rin River mouth in Satun (15W in Table 2), traverses the Thung Nui-Khao Phra Pass at the Satun-Songkhla border, and continues to Songkhla Lagoon (15E in Table 3) (Figure 5B and S4B). Other secondary routes connect Satun in southern Thailand to Perlis, Kedah, and Perak in Malaysia on the western coast, with Songkhla, Pattani, and Narathiwat in southern Thailand to Kelantan and Terengganu in Malaysia on the eastern coast.

The Southern Thai-Malay Peninsula (Zone 5)

This zone has three primary routes and four secondary routes (Table 1). These routes run from the mouth of the Muar River, the mouth of the Batu Pahat River, and the town of Sungai Punggor (22W to 24W in Table 2, respectively) in Johor to the mouth of the Rompin River in Pahang, the mouth of the Endau River between Pahang and Johor, and the mouth of the Mersing River in Johor (22E to 24E in Table 3, respectively) (Figure 6

and S5). These primary routes require between 23.5 and 28.5 hours, traversing 119 to 142 kilometers on foot. Other secondary routes in Malaysia connect the Malacca and Johor coastlines on the Strait of Malacca to the Pahang and Johor coastlines on the South China Sea.

In summary, the transpeninsula route simulations in this study yield 10 primary routes and 17 secondary routes (eight secondary routes from the western coast and nine secondary routes from the eastern coast) (Table 1). These routes were grouped into five zones following their spatial distribution that coincide with geographical features of the Thai-Malay Peninsula: two zones for the Kra and Kalah Isthmuses which separate three zones of peninsula's bulges in the northern, central, and southern parts (Figure 4-6).

Discussion

Simulated transpeninsula routes are likely to be associated with archaeological evidence and external historical records before the twelfth century AD. Archaeological evidence includes both systematically excavated sites and academic and government reports of surface findings, while historical records include those written in Greek and Chinese which contain sufficient geographical descriptions.

The Northern Thai-Malay Peninsula (Zone 1)

This first primary route (01W and 01E) is associated with many historic archaeological sites around the Tenasserim Mountains in western and central Thailand (e.g., Ban Don Ta Phet, U Thong, Khu Bua, Phong Tuek, and Nakhon Pathom) (Clarke 2014) (Figure 4A; Table 1). Ban Don Ta Phet, a burial site, contains bronze tools and sherds of Northern Black Polished Ware (NBPW) from northern India dating between the third and the second centuries BC (Glover 2018; Jacq-Hergoualc'h 2002, 80). Two high-tin

bronze bowls decorated with Indian art and dating to no earlier than the third century BC (Glover 2018; Glover and Jahan 2014; Jacq-Hergoualc'h 2002, 81) and several nephrite jade penannular or double-headed pendants (called lingling-o) believed to have been crafted in the Philippines were also discovered (Chaisuwan 2011; Glover 2018; Jacq-Hergoualc'h 2002, 81–84).

This primary route is also associated with toponyms that have appeared in historical records since the third century BC. Ptolemy's *Geōgraphikē Hyphēgēsis*, composed in Greek around AD 150, describes *Bēsynga*, *Chrysē Chersonēsos*, and *Chrysē Chōra* (i.e., "the Golden Country") as belonging to the same region of India outside the Ganges. The Greek name *Bēsynga*, which may refer to the present-day city of Thaton or an area nearby in Myanmar, is likely identical to *Vesuṅga*, a port city mentioned in Indian records from the third century BC. According to Ptolemy's book, the land of the *Bēsyngitai* encompassed the coastline from the Gulf of Martaban to Victoria Point, the southernmost point of Myanmar, while *Chrysē Chersonēsos* is located next to it (McCrindle 1927, 196; Renou 1925, 44–45).

In another passage, *Chrysē Chōra* is described as being "juxtaposed to the *Bēsyngitai*" (McCrindle 1927, 219; Renou 1925, 53). *Chrysē Chōra,* or the Golden Country, has a similar meaning to the Sanskrit name *Suvarṇabhūmi* (i.e., "the Golden Land") found in Indian records from the third century BC. Modern scholars prefer to interpret this name as the entire region of Southeast Asia, as opposed to a specific area of a single country. Nevertheless, it is undeniable that in the early historic period, *Suvarṇabhūmi* was a port city comparable to *Takkola* and other contemporary toponyms. The similar meaning of the Chinese name *Jīnlín*, as the Golden Frontier, indicates that it is likely located in central Thailand, in which the Gulf of Thailand is also called *Jīnlín Dàwān* (i.e., the "Great Bay of *Jīnlín*") (Wheatley 2017, 15, 21–22,

116–117). In addition, the mouth of the *Sōbanos* River is mentioned in Ptolemy's book (McCrindle 1927, 202, 208; Renou 1925, 46). This river mouth is comparable to the mouth of the Chao Phraya River at Bangkok Bay in central Thailand, where its Greek name *Sōbanos* was likely derived from the Sanskrit prefix in *Suvarṇabhūmi*.

In contrast to the first primary route, no early historic archaeological sites have been reported near the second primary route through Thailand's Mawdaung-Singkhon Pass (02W and 02E) in which simulation results indicate that there may be undiscovered archaeological sites near its termini (Figure 4A; Table 1). However, there are some Chinese records from the third century AD mentioning two dependencies of Funan called *Bĭsōng* and *Diănxùn*, that might be located in this area on the Andaman Sea and the Gulf of Thailand, respectively (Wheatley 2017, 14–19, 21–23). *Bĭsōng*, in which its Cantonese pronunciation reads *Bei-sung*, is likely one of the port cities of *Vesuṅga* in Indian records or *Bēsynga* in Ptolemy's book. *Diănxùn* can be located at a coastal sailing distance of about 330 km north of Bandon Bay that is near the Samroi Yot National Park in Prachuap Khiri Khan in Thailand (Jacq-Hergoualc'h 2002, 33).

The Kra Isthmus (Zone 2)

Several archeological sites have been discovered near the Kra Isthmus in Myanmar and Thailand, close to the first primary route between Ranong and Chumphon (06W and 06E) (Figure 4B; Table 1). Khao Sam Kaeo near 06E in Chumphon is an important early historic site on the eastern coast (Bellina 2017b; Jacq-Hergoualc'h 2002, 82–83), with herds of earthenware, bronze tools, and iron tools frequently discovered here (Boer-Mah 2017; Bouvet 2017a; Jacq-Hergoualc'h 2002, 83; Pryce et al. 2017).

There are also additional indications of contact from both western and eastern regions. From the western region, many examples of Indian stoneware, ornaments made

from semiprecious stones and gold, and stone molds for casting metal ornaments were discovered (Bennett 2017, 64–65; Bouvet 2017b). Notable evidence includes a ringstone in the Maury-Sunga style (Bennett 2017, 63; Bennett 2018). Several semiprecious stone seals with Brahmi inscriptions from the same period (Borell and Falk 2017; Jacq-Hergoualc'h 2002, 83) and four high-tin bronze bowls engraved with Indian art (Bennett 2017, 20–23; Glover 2018; Glover and Jahan 2014) have also been found. In addition, large quantities of semiprecious stone, gold, and glass beads—as well as fragments of early Roman glassware manufactured in Egypt between the first and the third centuries AD—were recovered (Borell et al. 2014; Lankton and Gratuze 2018; Pongpanich 2009, 90–101).

From the eastern region, many lingling-o from Austronesian-speaking groups overseas and five bronze drums (also known as Don Son drums) from northern Vietnam were discovered (Bellina 2017a; Glover 2018; Hung and Iizuka 2017; Jacq-Hergoualc'h 2002, 75). Sherds depicting the Chinese manufacturing process during the Han dynasty in China, from the second to third century BC, were found (Bellina et al. 2014, 72–79; Favereau et al. 2017; Peronnet and Srikanlaya 2017). As Khao Sam Kaeo is located on the eastern side of the peninsula, western evidence suggests that the transpeninsula route may transport raw materials and commodities from India to the Mediterranean. In addition, eastern evidence suggests maritime trade within Southeast Asia and China. In conclusion, it is possible that this entrepôt flourished between the fourth century BC and the fourth century AD (Bellina 2017b; Jacq-Hergoualc'h 2002, 44, 83–84).

In contrast, no prominent archaeological site from the same period has been excavated on the western coast near 06W in Ranong. However, some reports of surface finds in Kawthaung, Myanmar, include several early historic sites such as Khamaukgyi, Aw Gyi, and Maliwan (Figure 4B). This area served as an ancient port city on the Kra

Isthmus, as evidenced by the discovery of glass beads and the remains of early Roman glassware from Egypt and the Levant (Bellina et al. 2018, 3; Dussubieux and Bellina 2017; Dussubieux et al. 2020; Pongpanich 2009, 195). Khamaukgyi yielded a discstone resembling the Maury-Sunga ringstone in form and function and an Indian golden earring made with tiny, granulated gold beads (Bennett 2017, 70). Also discovered were fragments of rouletted ware from southern India and Han earthenware from China (Bellina et al. 2014, 79–85; Bellina et al. 2018, 4). The presence of Han ceramics and artifacts comparable to those found at Khao Sam Kaeo suggests that Kawthaung was likely its twin port city that flourished during the same period and was linked to Khao Sam Kaeo via the shortest routes across the Thai-Malay Peninsula (Jacq-Hergoualc'h 2002, 44).

The second primary route in this zone (09W and 09E) is associated with a group of early historic sites stretching from the Suk Samran District in Ranong, Thailand (including the Phu Khao Thong and Bang Kluai sites) to the Takua Pa District in Phang Nga (Figure 4B; Table 1). Several seals made of semiprecious stones and gold with Brahmi script were discovered on the surface, including the golden seal of a navigator found at Bang Kluai (Bennett 2017, 30–32; Bennett 2018). Golden ornaments (some made with tiny, granulated gold beads like those discovered at Khamaukgyi) and stone molds for casting metal ornaments were also found (Bennett 2017, 64–65, 70; Bennett 2018). The Bang Kluai site also yielded intaglios and cameos of Greco-Roman design that served as components of metal ornaments or amulets (Borell et al. 2014; Pongpanich 2009, 162–175).

At the nearby site of Phu Khao Thong, notable surface finds include sherds of Indian rouletted ware from the third to the first centuries BC and glass beads that were discovered alongside glass sherds, molten glass, and unfinished glass beads (Borell et

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al. 2014; Chaisuwan 2011; Pongpanich 2009, 154–175). Trace elements in these glasses are comparable to those of southern Indian glass at Arikamedu from the fourth to the second centuries BC and early Roman glass in Egypt and the Levant from the first to the third centuries AD (Borell et al. 2014; Chaisuwan 2011; Lankton and Gratuze 2018; Pongpanich 2009, 90–115, 154–175).

Suk Samran may also have been connected to archaeological sites associated with Khao Sek in Chumphon and Tha Chana in Surat Thani (near 09E). Glass beads and three bronze drums were discovered in the inland district of Phato (along the main route between 09W and 09E and a portion of the present-day highway no. 4006) (Pongpanich 2009, 194, 197, 216). Khao Sek on the Gulf of Thailand yielded lingling-o, a bronze drum, bronze and iron tools, semiprecious stone, gold, glass beads, and glass fragments. Similar artifacts, including lingling-o pendants, a bronze drum, semiprecious stone beads, and early Roman glass beads, were also discovered at Tha Chana, approximately 80 km south of Khao Sek (Borell et al. 2014; Chaisuwan 2011; Fine Arts Department 1991, 323–324; Fine Arts Department 2002, 29–31, 37; Pongpanich 2009, 102–115). Hindu remains were also be found in Tha Chana, including brick buildings and stone statues (Fine Arts Department 2002, 37, 88–89; Jacq-Hergoualc'h 2002, 130–131). These indicate that the proposed transpeninsula route between 09W and 09E does exist. Studies suggest that Suk Samran, Khao Sek, and Tha Chana may have been inhabited between the second century BC and the seventh century AD (Lankton and Gratuze 2018; Pongpanich 2009, 230–231).

Both Kawthaung in Myanmar and Ranong in Thailand have been proposed to be the most likely location of the ancient Andaman emporium of *Takkola*, mentioned in Buddhist texts around the third century BC and as *Takōla* in Ptolemy's *Geōgraphikē Hyphēgēsis* from the second century AD (Borell 2018; Koad and Rakmak 2022; Koad

et al. 2023; Wheatley 2017, 138, 181, 269). In this Greek record, *Takōla* is listed as the first toponym in *Chrysē Chersonēsos*, following "promontory beyond *Bērabai*," the final toponym in the land of the *Bēsyngitai* (McCrindle 1927, 196; Renou 1925, 44–45). *Bērabai* is most likely located in the present-day city of Dawei or a nearby area in Myanmar, while the promontory beyond that city is Victoria Point in Kawthaung, the southernmost point of Myanmar. As such, *Takōla* in the time of Ptolemy, which was located beyond this promontory, should be situated in Ranong in southern Thailand (possibly at the Suk Samran archaeological complex) rather than Kawthaung in southern Myanmar.

However, it is important to note that analysis of subsequent historical records in Chinese and Arabic indicates that *Takkola* or *Takōla* territory once extended along the Andaman Sea coast from the northernmost island of Mali in the Mergui Archipelago in Myanmar to Cape Promthep on Phuket in Thailand (Koad and Rakmak 2022; Koad et al. 2023). This name also has many variants in other languages: *Dōulú* in Han Chinese (the second century AD), *Dōukūn* in post-Han Chinese (from the mid-third century AD onward), *Talaittakkolam* in Tamil (the eleventh century AD), and *Ujong Salang* in Malay (before the thirteenth century AD, designated the coastline from Phang Nga to Phuket) (Koad and Rakmak 2022). The spatiotemporal analysis of these toponyms and the unearthed archaeological evidence support the hypothesis that *Takkola*'s commercial center migrated southward over time (Chaisuwan 2011; Koad and Rakmak 2022).

The circum-peninsula route through the Malacca Strait has existed at least since the start of the Christian era, as Chinese records mention *Pízōng*, which is most likely located in eastern Sumatra, where the Srivijaya kingdom emerged in the seventh century AD (Jacq-Hergoualc'h 2002, 48, 50; Wheatley 2017, 11–12). Furthermore, it is possible

that westerners also completed this circumnavigation, as geographical knowledge of Sumatra, Java, western Borneo, and the Andaman and Nicobar Islands is described in Ptolemy's book after the account of mainland Southeast Asia (McCrindle 1927, 236, 239; Renou 1925, 58–61). These findings indicate that transpeninsula routes traversing the Thai-Malay Peninsula existed alongside the circum-peninsula route through the Malacca Strait as early as 2000 years ago. This could be due to the benefit and worthiness of traversing the peninsula, which would avoid pirates and save travel costs. The circum-peninsula route was likely used to primarily transport rare and local goods from Island Southeast Asian. It is in the later period that the emergence of other more powerful states such as *Pánpán* and Srivijaya forced transpeninsula routes to shift southward or even to be abandoned because of the increase in circum-peninsula traffic.

The Central Thai-Malay Peninsula (Zone 3)

A secondary route through the Ratchaprapha Reservoir in Surat Thani (10W to 10E) suggests the connection between a group of early historic sites in Suk Samran, Khura Buri, and Takua Pa on the Andaman Sea to Chaiya and Phunphin around Bandon Bay (Figure 5A; Table 1). Khura Buri District in Phang Nga, 20 km south of Suk Samran, contains archaeological sites where bronze and iron tools, sherds of earthenware, semiprecious stone beads, and glass beads (some made of the early to the middle period of the Roman glass from the first to the sixth centuries AD) were discovered (Fine Arts Department 1991, 246–249; Lankton and Gratuze 2018; Pongpanich 2009, 176–189, 192–193).

Approximately 40 km south of Khura Buri is a group of archaeological sites in the Takua Pa District in Phang Nga (e.g., Thung Tuek and Khao Phra Noe). Here, beads from a later period, similar to that of Khura Buri, were discovered, as well as Hindu stone statues dated to no later than the eighth century AD, remains of brick buildings,

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Buddhist votive tablets, and sherds of ceramics from China and the Middle East (Chaisuwan 2011; Fine Arts Department 1991, 225–228, 244–245, 248–249, 252–253; Jacq-Hergoualc'h 2002, 44, 124–127, 284–294, 308–310, 328–331; Pongpanich 2009, 128–135).

At Bandon Bay in the Gulf of Thailand, evidence from the Chaiya District in Surat Thani includes a bronze drum, glass beads (especially from the later period similar to those of Khura Buri and Takua Pa), sherds of Chinese ceramic from the Tang period (from the eighth to the ninth centuries AD), Chinese and Arab coins, numerous stone and bronze statues in both Buddhism and Hinduism dating from the sixth to the twelfth centuries AD, stone inscriptions, and a group of brick buildings dated to the same period (Chaisuwan 2011; Fine Arts Department 2002, 37–41, 58–64, 67–88; Indorf 2014; Jacq-Hergoualc'h 2002, 44, 75, 147, 149–154, 280–283, 302–307, 311–314; Lavy 2014; Pongpanich 2009, 116–127, 197).

Nonetheless, the shorter secondary route may be the long proposed Takua Pa-Bandon Bay route, which is currently highway no. 401 (Chaisuwan 2011; Fine Arts Department 2002, 24; Jacq-Hergoualc'h 2002, 35–37, 44) (Figure 5A). Archaeological evidence and surface discoveries indicate that the transpeninsula route between Khura Buri, Takua Pa, and Bandon Bay existed during the early historic period and gained prominence during the Srivijaya period between the seventh and the twelfth centuries AD.

A secondary route from Bandon Bay to the Marui River (11E to 11W) is associated with a cluster of potential historic sites around Phang Nga Bay on the Andaman Sea, where stone ornaments, bronze and iron tools, and sherds of earthenware were discovered (Figure 5A; Table 1) (Fine Arts Department 1991, 31–48, 198–199, 225–228, 244–256). An archaeological complex near 11E in the Phunphin District in

Surat Thani (including the Khao Si Wichai and Khuan Saranrom sites) provides artifacts such as bronze and iron tools, two bronze drums, beads similar to those of Chaiya, Arab coins from the eighth century AD, Chinese ceramics from the Song period (from the tenth to the thirteenth centuries AD), stone and bronze statues in both Buddhism and Hinduism dating to the seventh and the eighth centuries AD, Buddhist votive tablets, and remains of brick buildings were found (Chaisuwan 2011; Fine Arts Department 2002, 29–31, 37, 94–100; Jacq-Hergoualc'h 2002, 75, 116–118, 121–122, 145, 150–155, 307–308, 313–316). Although this northeast-to-southwest route (now part of highways 44, 401, and 415) has been suggested as a potential transpeninsula route (Fine Arts Department 2002, 24), evidence from different periods between Phang Nga Bay and Phunphin does not strongly support the use of this secondary transpeninsula route.

Along the first primary route in this zone (12W and 12E), the archaeological complex at Khlong Thom District in Krabi on the Andaman Sea (including Khuan Lukpad and other nearby sites) is well-known among archaeologists for its function as an ancient bead production site, which has been both illegally looted and legally excavated in modern times (Figure 5A; Table 1). Archaeological evidence and surface finds include bronze and iron tools, sherds of earthenware and stoneware, and sherds of Middle Eastern and Chinese ceramics from the eighth to the ninth centuries AD (Chaisuwan 2011; Fine Arts Department 1991, 16–18; Jacq-Hergoualc'h 2002, 84–85). Indian merchants' seals made from semiprecious stones and gold with Brahmi and Pallava inscriptions dating from the third to the seventh centuries AD, as well as a goldsmith's touchstone bearing Tamil inscription, were discovered (Chaisuwan 2011; Jacq-Hergoualc'h 2002, 85–87). Roman intaglios and cameos carved from semiprecious stones, along with an enormous quantity of beads from later period and their remains

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were also found (Borell et al. 2014; Chaisuwan 2011; Jacq-Hergoualc'h 2002, 87–89; Pongpanich 2009, 136–153, 196).

Some studies have proposed a possible north-south oriented transpeninsula route between Khlong Thom and Bandon Bay (Fine Arts Department 2002, 24; Jacq-Hergoualc'h 2002, 35–37, 45–46). Wiang Sa, however, has yielded no evidence comparable to these areas, with the exception of Buddhist and Hindu stone statues dating between the seventh and the twelfth centuries AD (Fine Arts Department 2002, 38, 105–108; Jacq-Hergoualc'h 2002, 120–121, 143–144). This raises the possibility that a 150 km transpeninsula route through Wiang Sa, if it existed in the early historic period, only served as a local route for transporting inland resources to nearby port cities.

Three bronze drums from the early historic period were also discovered near the Nakhon Si Thammarat Range in Nakhon Si Thammarat on the Gulf of Thailand (Fine Arts Department 2000, 19–20; Jacq-Hergoualc'h 2002, 75). However, the majority of early historic artifacts, such as bronze and iron tools, bronze and gold ornaments, and beads comparable to those discovered at Khlong Thom, were discovered along a 70 km-long area east of the Nakhon Si Thammarat Range, beginning with the archaeological complex of Tha Ruea near 12E and ending with that of Sichon District (Fine Arts Department 2000, 20–21). Stone and bronze statues of Buddhism and Hinduism and sherds of Tang ceramics between the sixth and the twelfth centuries AD were discovered at the Tha Ruea complex. In contrast, at the Sichon complex, the majority of religious artifacts were Hindu in nature and were found with the remains of brick buildings (Fine Arts Department 1991, 70–120; Fine Arts Department 2000, 20–35, 171–186; Indorf 2014; Jacq-Hergoualc'h 2002, 75, 118–120, 123, 129–133, 144–149, 308, 319–320; Lavy 2014). Between these two archaeological complexes are several

contemporary archaeological sites where numerous artifacts, including important inscriptions and stupas, were discovered (Fine Arts Department 2000, 36–39, 62–70, 145–170). Note that the distance of the proposed Khlong Thom-Bandon Bay route is longer than that of the primary route through the Krarom Pass by approximately 30 km, indicating a possible connection between Khlong Thom and Tha Ruea (Jacq-Hergoualc'h 2002, 46–47).

Along the primary route between Trang and Phatthalung (14W and 14E), numerous Buddhist votive tablets and stupas, as well as a few bronze Buddhist statues from the Srivijaya period, were discovered (Figure 5A; Table 1) (Fine Arts Department 1991, 264–300; Jacq-Hergoualc'h 2002, 46–47, 155–159, 321–322, 331–332). In addition, the Sathing Phra Peninsula, which separates Thale Luang from the Gulf of Thailand (Figure 5A and 5B), is home to a nearby collection of early historical sites. Sherds of earthenware, stoneware, and Chinese porcelains, semiprecious stone, glass, and gold beads, tin, bronze, and gold ornaments, baked clay seals, stone and both Buddhist and Hindu bronze statues, Buddhist votive stupas, and stone molds for making Buddhist votive tablets were also discovered in the Ranot and Sathing Phra Districts of the Sathing Phra Peninsula (Fine Arts Department 2014, 196–243, 428–442; Jacq-Hergoualc'h 2002, 120, 133–134, 146–147, 308, 321–325).

Around Bandon Bay in Surat Thani, there was another dependency of Funan called *Gōuzhì* in Chinese records of the third century AD (Wheatley 2017, 14–15, 19, 23–24). This country likely expanded its territory to include nearby land in the central Thai-Malay Peninsula (including *Dōukūn* or the port on the Andaman Sea called *Takkola* and *Takōla*) from the Kra Isthmus to the Kalah Isthmus and was later called *Pánpán* that sent envoys to China several times between the fifth to seventh century AD (Wheatley 2017, 48–49, 57, 254). Chinese records also stated that its capital city had a

moated wooden wall that are probably remnants of the Wiang Sa archaeological site located at the center of this zone (Fine Arts Department 2002, 106). It is possible that the rise of *Pánpán* forced the transpeninsula routes at its border around the Kra Isthmus (Figure 4B) to shift southward to the central Thai-Malay Peninsula (Figure 5A). This shifting towards Wiang Sa can be implied from the last period of Khao Sam Kaeo in the fourth century AD followed by the first mention of *Pánpán* in the fifth century AD (Bellina 2017b, 648–661; Jacq-Hergoualc'h 2002, 44, 83–84; Lankton and Gratuze 2018, 67–77; Pongpanich 2009, 230–231).

Note much later, European maps of the nineteenth century AD depict the Sathing Phra Peninsula as a large island named *Tantalem*, where one can sail from Nakhon Si Thammarat to Phatthalung and Songkhla without embarking (Jacq-Hergoualc'h 2002, 10). However, this interpretation is not unique. The Chinese have viewed the Sathing Phra Peninsula as a large island and country named *Bólà* since the Sui dynasty (from the late sixth to early seventh centuries AD). This Chinese name has a similar pronunciation to the second-century AD city of *Perimoula* mentioned in Ptolemy's work (McCrindle 1927, 197–198; Renou 1925, 45–46). This book also describes that to the north of *Perimoula* is the *Perimoulos* Gulf (the gulf beyond *Perimoula*), which is most likely Bandon Bay. These findings suggest that the Sathing Phra Peninsula flourished at least as early as the second century AD, possibly in conjunction with a transpeninsula route in this region.

The Kalah Isthmus (Zone 4)

Sherds of earthenware and stoneware and monochrome glass beads were discovered on land and nearby islands in Satun on the Andaman Sea which is the terminus of a primary route (15W and 15E) (Figure 5B; Table 1) (Fine Arts Department

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2014, 402–421). Several potential inland historic sites containing sherds of earthenware, bronze vessels, and monochrome glass beads have been discovered at Songkhla on the Gulf of Thailand (Fine Arts Department 2014, 196–243). Unfortunately, there are only a few artifacts from the Songkhla mainland near 15E and 16E, including two bronze drums from the early historic period and Buddhist and Hindu bronze statues from the Srivijaya period (Jacq-Hergoualc'h 2002, 47, 321). However, another group of Srivijaya-era artifacts includes the remains of a brick stupa discovered at the Wat Khao Noi site, located at the southernmost tip of the Sathing Phra Peninsula.

All secondary routes in this zone may also be associated with archaeological sites in the Yarang District, Pattani, Thailand, and southern Kedah and Kuala Selinsing, Perak, Malaysia (Figure 5B; Table 1) (Noonsuk 2014; Rahman et al. 2008; Ramli et al. 2009). At the archaeological complex of Yarang on the Gulf of Thailand, which flourished during the Srivijaya period, Buddhist and Hindu stone and bronze statues, a large number of Buddhist votive stupas and tablets (some of which contain inscriptions written in Pallava scripts from the eighth century AD), the remains of brick buildings, coins from China and the Middle East, and sherds of Persian ceramics were discovered (Fine Arts Department 1991, 136–138; Indorf 2014; Jacq-Hergoualc'h 2002, 47–48, 166–191, 283–284, 327–328; Noonsuk 2014).

At the archaeological complex in southern Kedah along the Malacca Strait (which includes several sites such as the renowned Bujang Valley), a large number of artifacts indicating the possible existence of the early historic metal industry in this area were discovered, along with commercial and religious artifacts from the Srivijaya period. These include many later period glass beads similar to those of Takua Pa and Chaiya, and ceramic sherds from China and the Middle East (Jacq-Hergoualc'h 2002, 47–48, 203–229, 294–300, 310–311).

Kuala Selinsing in Perak, about 90 km south of the southern Kedah complex, has also been proposed as a significant bead production site due to the discovery of a large number of later period semiprecious stone and glass beads similar to those of Khlong Thom, along with stone, bronze, and iron tools, sherds of earthenware and Indian stoneware, a carnelian seal inscribed with Pallava scripts from the sixth century AD, and a gold ring (Jacq-Hergoualc'h 2002, 90–91).

The geographical location of the *Sabana* emporium given in Ptolemy's book of the second century AD are the earliest written evidence of early human settlement in southern Kedah (Borell 2018; Wheatley 2017, 138). However, analysis using astronomical and geographical computations suggests that the location of this emporium in the majority of recensions is incorrect (missing an arcminute symbol), which also contributes to the unseemly reconstruction of maps in the modern era. After correcting this error, the location of the *Sabana* emporium coincides with that of Kedah.

The Greek name *Sabana* was probably transcribed and shortened from the Sanskrit name *Suvaṇṇakaṭa* that appears alongside *Suvarṇabhūmi* and *Takkola* in Indian texts from the third century BC (Borell 2018; Wheatley 2017, 181, 269). Its suffix "*kaṭa*" was likely the predecessor of the Sanskrit name *Kaṭāha* from the seventh to the eleventh centuries AD as well as its variants, including *Jiéchá* in Chinese (the seventh century), *Kaḍāram* in Tamil (the eleventh century AD), *Kalāh*, *Kalahī*, *Qala'ī*, and *Qal'ī* in Arabic (from the eighth to the twelfth centuries AD), *Gēluó* in Chinese (from the eighth to the twelfth centuries AD), and *Grahi* on a bronze Buddhist statue found at Chaiya in Surat Thani (the twelfth century AD) (Bennett 2018; Koad and Rakmak 2022; Koad et al. 2023; Wheatley 2017, 216–220).

During the historical period, the ancient settlement of Kedah became an important port city on the Kalah Isthmus as there is textual evidence confirming the

direct crossing of the Indian Ocean in the mid-seventh century AD (Wheatley 2017, 41–42, 278). From this location, one can take a transpeninsula route across the Kalah Isthmus or continue south through the Malacca Strait near modern-day Singapore if the circum-peninsula travel is intended. During the Srivijaya period, Kedah still maintained its potential to be the center of commerce, especially for local products like tin, a precious metal that can be mined from the nearby Titiwangsa Mountain (Wheatley 2017, 238).

The power of Srivijaya that extended into the Thai-Malay Peninsula sometime between the seventh and eight centuries AD, as well as the emergence of a sailing route across the Indian Ocean, probably led to the increase in the circum-peninsula route through the Malacca Strait. Srivijaya secured its supremacy by limiting piracy here and promoting Kedah to be the endpoint after crossing the Indian Ocean, as well as the gateway to China. This ultimately further decreased the use of transpeninsula routes across the Kra Isthmus and the central Thai-Malay Peninsula during this period.

The Southern Thai-Malay Peninsula (Zone 5)

In this zone, bronze and iron tools, bronze drums, bronze bells, and glass beads were unearthed in Selangor, particularly at the Bernam Valley site on the coast of the Malacca Strait (Figure 6; Table 1). Similar artifacts were also discovered on the South China Sea coast at Kuala Terengganu (Jacq-Hergoualc'h 2002, 75, 77; Ramli et al. 2009). However, the archeological sites in Bernam Valley and Kuala Terengganu are too far away to be definitively linked to any transpeninsula route. This indicates that both locations lacked direct communication and relied on the sea for trade. Sungai Lang in Selangor, Kampung Pencu in Johor, and along the Johor River, notably Johor Lama and Kota Tinggi in the southernmost portion of the Thai-Malay Peninsula, yielded a large number of glass beads dating to the early historic period (Jacq-Hergoualc'h 2002,

75, 77; Ramli et al. 2009) (Figure 6). A bronze drum was also discovered near 21E in the modern city of Pahang (Jacq-Hergoualc'h 2002, 75).

These bead sites indicate that in the early historical period of Southeast Asia, this region also served as nexus for trade and exchange. Since merchants and travelers could easily sail between the eastern and western coasts, only locals likely utilized transpeninsula routes in this zone during the early historic period. In Chinese records from the mid-fourth century AD, *Gēyíng* and *Jiāchén* are two countries that were located within this zone. *Gēyíng* in Pahang were frequently mentioned as a stop along the coastal sailing route, while *Jiāchén* to the southwest of *Gēyíng* in the Malacca Strait was said to have shallow water and rampant piracy. This description of shallow water and pirates indicates that there existed a circum-peninsula route in which sailors were acquainted with the local bathymetry of the Malacca Strait and that their ships carried merchandise valuable enough to be plundered.

The results from simulations of transpeninsula routes in this study are consistent with archaeological evidence and foreign historical records before the twelfth century AD. Several routes previously proposed by scholars are supported by these simulated routes, including those surrounding the Kra Isthmus, the Takua Pa-Bandon Bay route, and the Kalah Isthmus. In addition, the results suggest potential routes that require additional research and confirming evidence.

Conclusions

Our study sheds light on the distribution and connections of archaeological sites within the Thai-Malay Peninsula, which can be used to propose possible locations of ancient cities and emporia mentioned in Indian, Chinese, Greek, and Arab historical records. These data could also feasibly help with pinpointing the location of undiscovered sites

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and guiding future research.

However, using the resampled DEM dataset (which omits smaller inland waterways) and Tobler's hiking function (which does not account for the weight of the merchandise) causes simulation results to display an abnormally short travel time. When comparing routes, it is recommended that the ratio between the simulated walk time and the minimum walk time across the Kra Isthmus be used, which is approximately 9.8 hours along the primary route between 06W and 06E (Figure 4B; Table 1). For example, the primary route between 15W and 15E across the Kalah Isthmus takes approximately 15.8 hours, which is 1.6 times longer than the Kalah Isthmus. (Figure 5B; Table 1).

This research also suggests some potential enhancements that could produce more accurate results. These include: 1) increasing the spatial resolution of the DEM dataset used to perform simulations that include smaller rivers; 2) assimilating the bathymetry data of artificial water bodies (such as the Ratchaprapha Reservoir in Thailand and the Pedu Reservoir in Malaysia) into the DEM dataset used to perform the simulation to avoid the abnormally short walking time; 3) using the modified or another available cost function that accounts for the rough terrain and the load of the merchandise; and 4) modify the pathfinding algorithm so that one can use safe waterways to shorten the travel time across the Thai-Malay Peninsula. Despite these shortcomings, the present research provides important insights into potential trade routes regionally and avenues for future research, particularly as they relate to as yet undiscovered sites.

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Figure Caption

Figure 1. Relief map of DEM used in the simulation of transpeninsula routes (derived from ASTER GDEM version 3). Eastern and western coastlines are shown as blue lines. The maximum limit was 300 m above the mean sea level (red contour lines). Modern-day political boundaries are shown as dashed lines.

Figure 2. Graphs showing walk pace (A) and walk speed (B) from Tobler's hiking function, assuming the walk is along a straight line over flat terrain.

Figure 3. Snapshots from the example simulation of a transpeninsula route from a point at the Andaman Sea coast at walk times of 4.5 hours (A) and 27.21 hours (B). Simulated routes from a starting point (a green dot in A) resemble the structure of a sea fan (A) where active routes (blue lines) are expanding outward, and terminated routes (red) are left inside. As the walk time advances, the first active route that reaches a point on the Gulf of Thailand coast will be selected as the time-optimized route between 2 points (a green line connecting two green dots in B). Black dots in B approximate contour lines of walk time every 5 hours.

Figure 4. Maps showing simulated transpeninsula routes across the northern Thai-Malay Peninsula (Zone 1, A) and the Kra Isthmus (Zone 2, B). In each zone, all simulated routes between eastern and western coasts are shown as black lines, while their secondary routes are shown in colors representing the estimated walk time. Destinations shown in grey labels are secondary routes, while those in yellow are primary routes. Yellow dots are prominent archaeological sites or complexes mentioned

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in this study, while magenta and cyan represent prehistoric and early historic archaeological sites, which are currently publicly available in Thailand, respectively. (Geographical coordinates of prehistoric and early historic archaeological sites in Thailand are available in http://gis.finearts.go.th/fineart/). In the northern Thai-Malay Peninsula (A), only archaeological sites longitude of less than 100.3° E are shown.

Figure 5. Maps showing simulated transpeninsula routes across the central Thai-Malay Peninsula (Zone 3, A) and the Kalah Isthmus (Zone 4, B).

Figure 6. Maps showing simulated transpeninsula routes across the southern Thai-Malay Peninsula (Zone 5).

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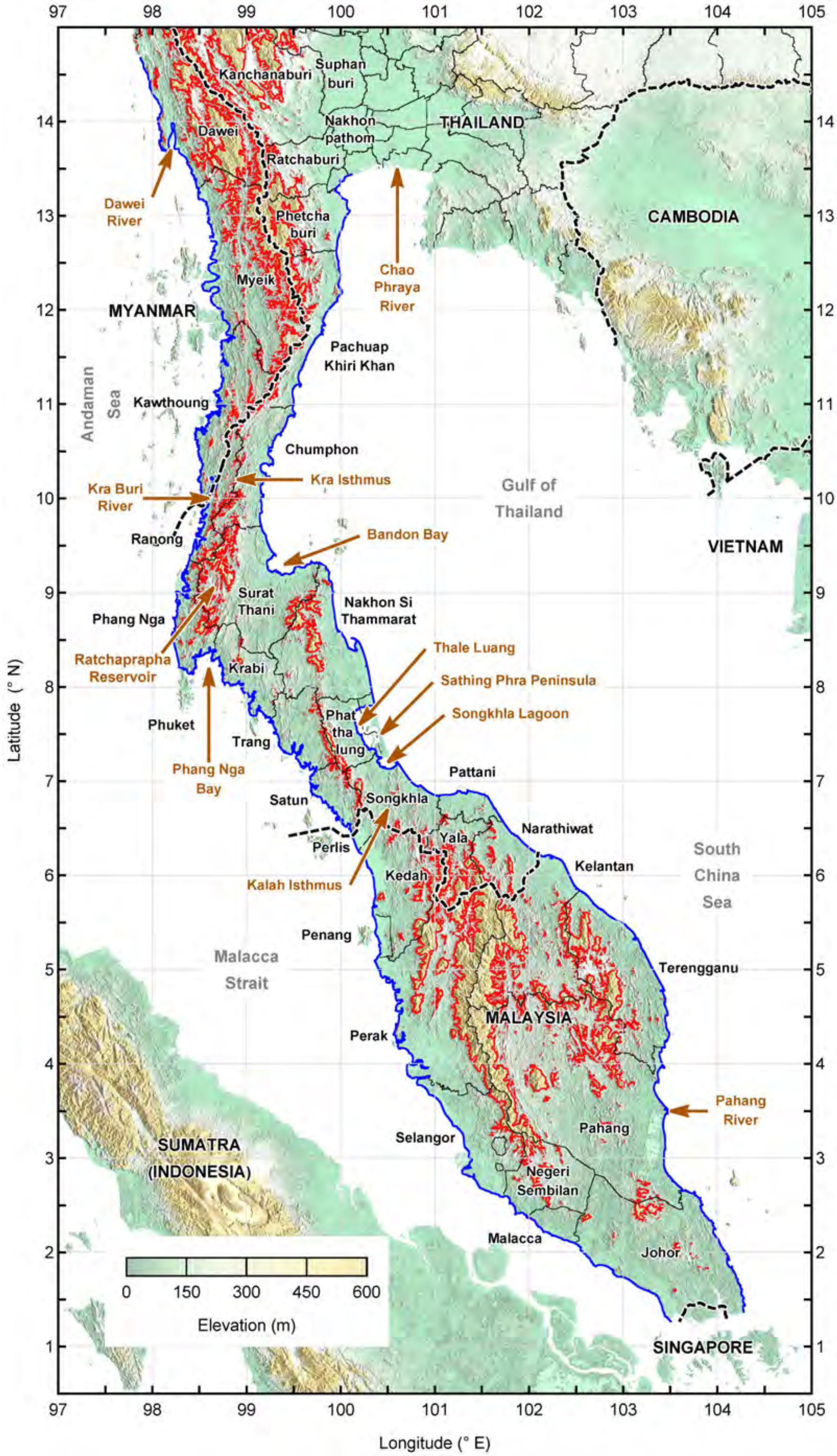

Figure 1

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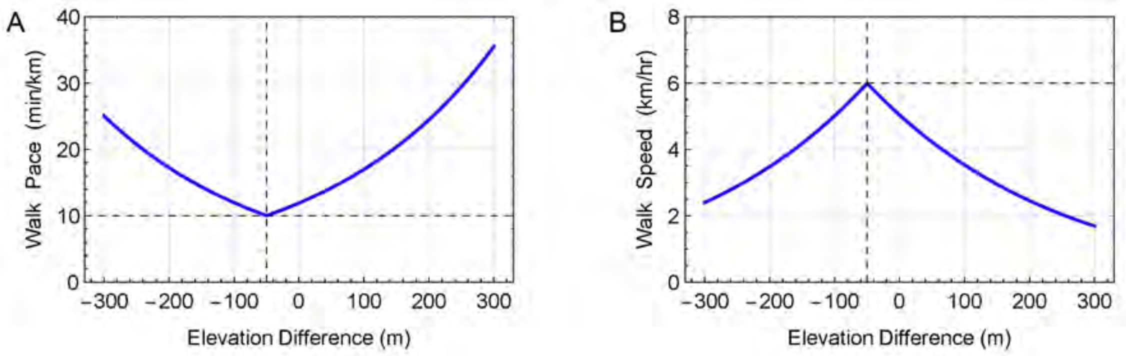

Figure 2

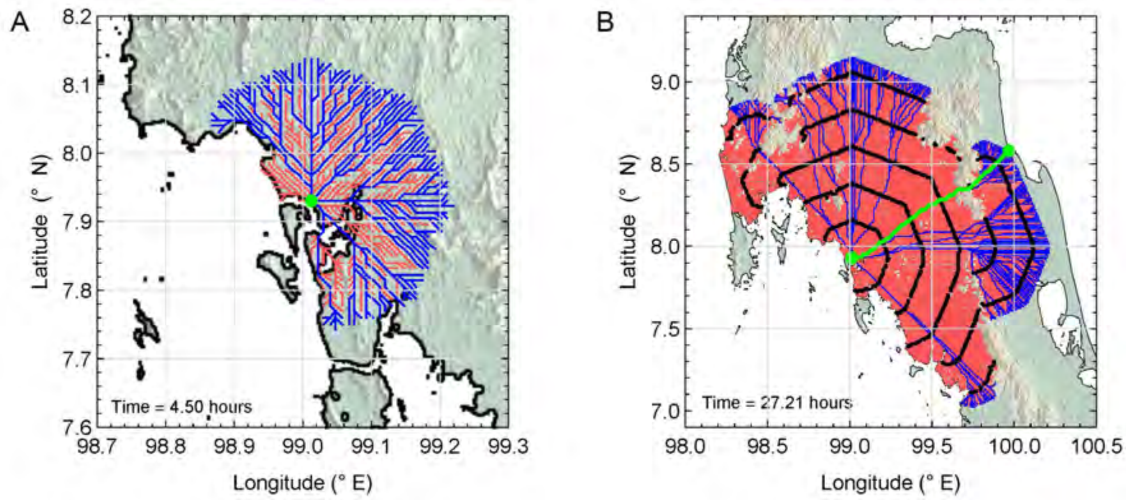

Figure 3

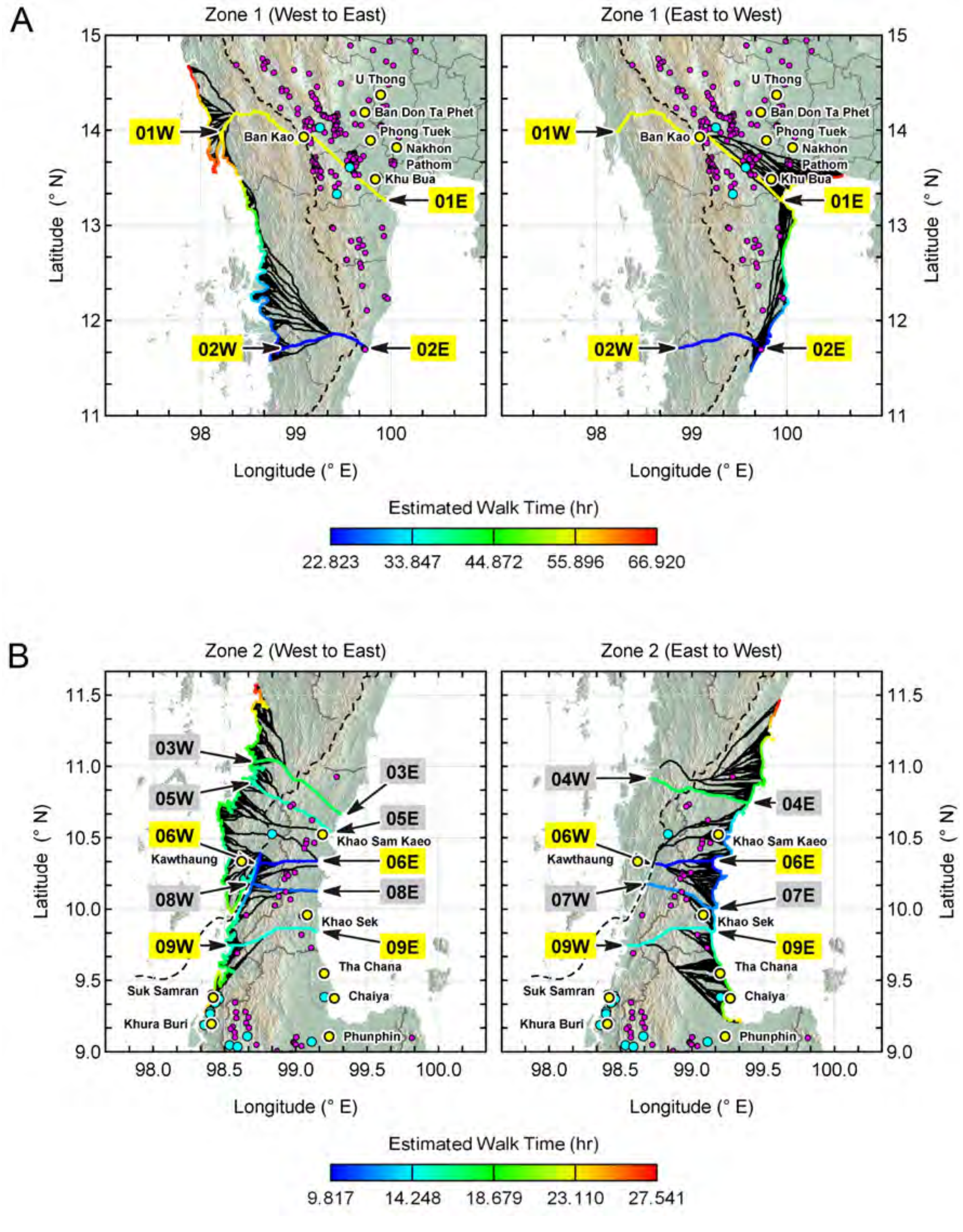
A
Zone 1 (West to East)
Zone 1 (East to West)
01W
01E
02W
02E
U Thong
Ban Don Ta Phet
Ban Kao
Phong Tuek
Nakhon
Pathom
Khu Bua
Latitude (° N)
Longitude (° E)
Estimated Walk Time (hr)
22.823
33.847
44.872
55.896
66.920
B
Zone 2 (West to East)
Zone 2 (East to West)
03W
03E
04W
04E
05W
05E
06W
06E
07W
07E
08W
08E
09W
09E
Khao Sam Kaeo
Kawthaung
Khao Sek
Tha Chana
Suk Samran
Chaiya
Khura Buri
Phunphin
Estimated Walk Time (hr)
9.817
14.248
18.679
23.110
27.541

Figure 4

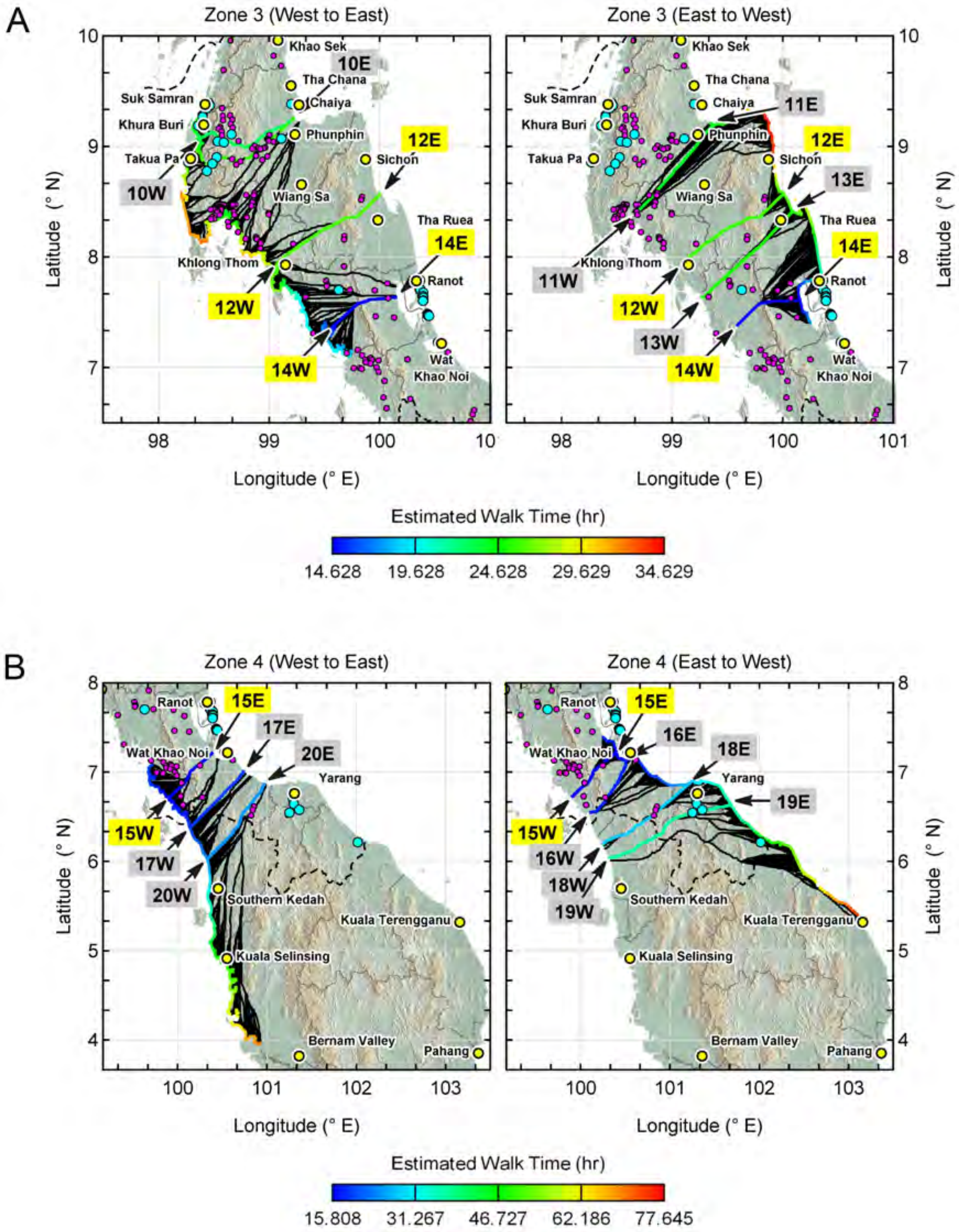
A
Zone 3 (West to East)
Zone 3 (East to West)
Khao Sek
Tha Chana
Chaiya
Suk Samran
Khura Buri
Takua Pa
Phunphin
Sichon
Wiang Sa
Tha Ruea
Khlong Thom
Ranot
Wat Khao Noi
10E
11E
12E
13E
14E
10W
11W
12W
13W
14W
Latitude (° N)
Longitude (° E)
Estimated Walk Time (hr)
14.628
19.628
24.628
29.629
34.629
B
Zone 4 (West to East)
Zone 4 (East to West)
Ranot
Wat Khao Noi
Yarang
Southern Kedah
Kuala Terengganu
Kuala Selinsing
Bernam Valley
Pahang
15E
16E
17E
18E
19E
20E
15W
16W
17W
18W
19W
20W
Latitude (° N)
Longitude (° E)
Estimated Walk Time (hr)
15.808
31.267
46.727
62.186
77.645

Figure 5

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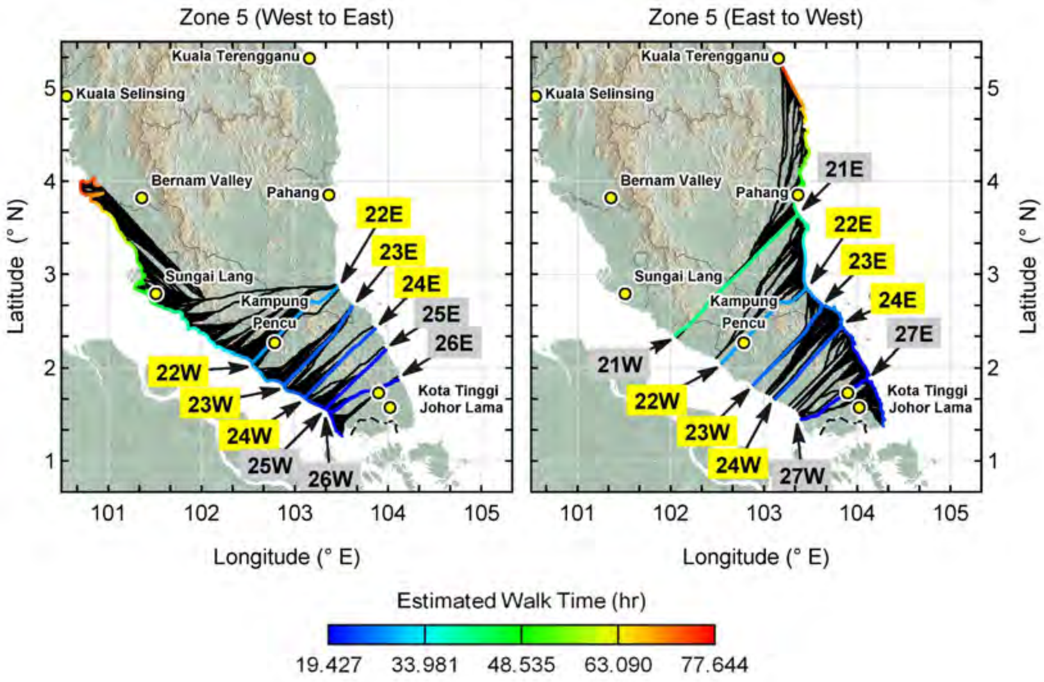

Figure 6

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Table Caption

Table 1. Summary of main transpeninsula routes across the Thai-Malay Peninsula. Each site is named with a 2-digit number to indicate its corresponding destination on another coast, followed by “E” or “W” to represent the eastern and western coasts, respectively. Arrows indicate the direction of transpeninsula routes. Primary routes are shown as blue and boldface texts. “Rm.” and “Rms.” are abbreviations of “River mouth” and “River mouths” respectively.

Table 2. Details and geographical coordinates of transpeninsula routes’ destinations on the western coast (the Andaman Sea and the Malacca Strait) as shown in Table 1. The first to third administrative divisions of Myanmar are region, district, and township, that of Thailand are province, district, and subdistrict, and that of Malaysia are state, district, and mukim.

Table 3. Details and geographical coordinates of transpeninsula routes’ destinations on the eastern coast (the Gulf of Thailand and the South China Sea) as shown in Table 1. The first to third administrative divisions of Myanmar are region, district, and township, that of Thailand are province, district, and subdistrict, and that of Malaysia are state, district, and mukim.

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Table 1.

Western Coast (Andaman Sea and Malacca Strait)					Eastern Coast (Gulf of Thailand and South China Sea)			
Site	**Country**	**Time (hr)**	**Name**	**Distance (km) and Direction**	**Name**	**Time (hr)**	**Site**	**Country**
Zone 1: Northern Thai-Malay Peninsula								
Tavoy Rm.	**Myanmar**	**55.370**	**01W**	**← 269 →**	**01E**	**55.290**	**Bang Tabun Rm.**	**Thailand**
Lenya Rm.	**Myanmar**	**22.823**	**02W**	**← 110 →**	**02E**	**22.962**	**Wa Thon Rm.**	**Thailand**
Zone 2: The Kra Isthmus								
Hangapru	Myanmar	-	03W	85 →	03E	17.352	Bang Son Bay	Thailand
Hankadin	Myanmar	17.230	04W	← 84	04E	-	Yai Ai Rm.	Thailand
		-	05W	74 →	05E	15.350	Phanang Tak Bay	Thailand
Lam Liang Rm.	**Thailand**	**9.859**	**06W**	**← 47 →**	**06E**	**9.817**	**Thung Kha-Sawi Bay**	**Thailand**
La-un Rm.	Thailand	12.354	07W	← 60	07E	-	Riu Rm.	Thailand
		-	08W	54 →	08E	11.381	Tako Rm.	Thailand
Son Bay	**Thailand**	**14.871**	**09W**	**← 73 →**	**09E**	**14.835**	**Bang Man Rm.**	**Thailand**
Zone 3: Central Thai-Malay Peninsula								
Phra Thong Island	Thailand	-	10W	115 →	10E	22.920	Tha Chang-Phunphin Rms.	Thailand
Marui Rm.	Thailand	23.998	11W	← 122	11E	-	Tapi Rm.	Thailand
Phela-Khlong Thom Rms.	**Thailand**	**25.744**	**12W**	**← 130 →**	**12E**	**26.045**	**Tha Phae Rm.**	**Thailand**
Kalase Yai Rm.	Thailand	25.051	13W	← 127	13E	-	Pak Phanang Bay	Thailand
Trang-Palian Rms.	**Thailand**	**14.721**	**14W**	**← 73 →**	**14E**	**14.628**	**Lam Pam Rm.**	**Thailand**
Zone 4: The Kala Isthmus								
Baraket-Thung Rin Rms.	**Thailand**	**15.808**	**15W**	**← 80 →**	**15E**	**15.809**	**Songkhla Lagoon**	**Thailand**
Tha Chin Rm.	Thailand	17.802	16W	← 89	16E	-	Songkhla Lagoon	Thailand
Perlis Rm.	Malaysia	-	17W	99 →	17E	19.553	Na Thap Rm.	Thailand
Jerlun	Malaysia	28.021	18W	← 139	18E	-	Pattani Rm.	Thailand
Kedah Rm.	Malaysia	36.671	19W	← 181	19E	-	Mai Kaen Rm.	Thailand
		-	20W	124 →	20E	24.812	Thepha Rm.	Thailand
Zone 5: Southern Thai-Malay Peninsula								
Baru Rm.	Malaysia	41.893	21W	← 211	21E	-	Penor Rm.	Malaysia
Muar Rm.	**Malaysia**	**28.440**	**22W**	**← 142 →**	**22E**	**28.402**	**Rompin Rm.**	**Malaysia**
Batu Pahat Rm.	**Malaysia**	**25.309**	**23W**	**← 127 →**	**23E**	**25.275**	**Endau Rm.**	**Malaysia**
Sungai Punggor	**Malaysia**	**23.896**	**24W**	**← 119 →**	**24E**	**23.592**	**Mersing Rm.**	**Malaysia**
Api Api	Malaysia	-	25W	101 →	25E	20.001	Tenggaroh	Malaysia
Pontian Besar Rm.	Malaysia	-	26W	99 →	26E	19.427	Mahkota Bay	Malaysia
Rimba Terjun	Malaysia	19.440	27W	← 99	27E	-		

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Table 2.

	Site	Township Subdistrict Mukim	District	Region Province State	Country	Latitude	Longitude
Zone 1: Northern Thai-Malay Peninsula							
01W	**Tavoy Rm.**	**Thayetchaung**	**Dawei**	**Tanintharyi**	**Myanmar**	**13° 59' 6" N**	**98° 13' 3" E**
02W	**Lenya Rm.**	**Bokpyin**	**Kawthaung**	**Tanintharyi**	**Myanmar**	**11° 42' 36" N**	**98° 52' 30" E**
Zone 2: The Kra Isthmus							
03W	Hangapru	Bokpyin	Kawthaung	Tanintharyi	Myanmar	11° 2' 6" N	98° 43' 57" E
04W	Hankadin	Bokpyin	Kawthaung	Tanintharyi	Myanmar	10° 55' 3" N	98° 43' 30" E
05W						10° 52' 57" N	98° 42' 54" E
06W	**Lam Liang Rm.**	**Bang Yai**	**Kra Buri**	**Ranong**	**Thailand**	**10° 19' 7" N**	**98° 45' 9" E**
07W	La-un Rm.	Sai Daeng	Mueang	Ranong	Thailand	10° 10' 21" N	98° 41' 42" E
08W							
09W	**Son Bay**	**Ratchakrut**	**Mueang**	**Ranong**	**Thailand**	**9° 44' 42" N**	**98° 33' 18" E**
Zone 3: Central Thai-Malay Peninsula							
10W	Phra Thong Island	Bang Wan	Khuraburi	Phang Nga	Thailand	9° 4' 57" N	98° 23' 15" E
11W	Marui Rm.	(several)	Thap Put, Ao Luek	Phang Nga, Krabi	Thailand	8° 23' 24" N	98° 40' 3" E
12W	**Phela-Khlong Thom Rms.**	**(several)**	**Nuea Khlong, Khlong Thom**	**Krabi**	**Thailand**	**7° 56' 51" N**	**99° 5' 24" E**
13W	Kalase Yai Rm.	Khao Mai Kaeo	Sikao	Trang	Thailand	7° 37' 57" N	99° 16' 57" E
14W	**Trang-Palian Rms.**	**(several)**	**Kantang, Hat Samran**	**Trang**	**Thailand**	**7° 23' 6" N**	**99° 35' 33" E**
Zone 4: The Kala Isthmus							
15W	**Baraket-Thung Rin Rms.**	**(several)**	**Tha Phae, Mueang**	**Satun**	**Thailand**	**6° 43' 35" N**	**99° 54' 45" E**
16W	Tha Chin Rm.	Puyu	Mueang	Satun	Thailand	6° 32' 51" N	100° 6' 27" E
17W	Perlis Rm.	Kuala Perlis	-	Perlis	Malaysia	6° 22' 48" N	100° 8' 24" E
18W	Jerlun	Jerlun	Kubang Pasu	Kedah	Malaysia	6° 11' 42" N	100° 15' 9" E
19W	Kedah Rm.	Tebengau	Kota Setar	Kedah	Malaysia	6° 2' 42" N	100° 19' 30" E
20W						6° 1' 48" N	100° 19' 57" E
Zone 5: Southern Thai-Malay Peninsula							
21W	Baru Rm.	Kuala Sungai Baru	Alor Gajah	Melaka	Malaysia	2° 20' 42" N	102° 3' 9" E
22W	**Muar Rm.**	**Kesang, Muar**	**Tangkak, Muar**	**Johor**	**Malaysia**	**2° 3' 27" N**	**102° 33' 0" E**
23W	**Batu Pahat Rm.**	**Bagan, Minyak Beku**	**Batu Pahat**	**Johor**	**Malaysia**	**1° 49' 12" N**	**102° 53' 24" E**
24W	**Sungai Punggor**	**Sungai Punggor**	**Batu Pahat**	**Johor**	**Malaysia**	**1° 40' 26" N**	**103° 6' 54" E**
25W	Api Api	Api Api	Pontian	Johor	Malaysia	1° 33' 36" N	103° 19' 57" E
26W	Pontian Besar Rm.	Api Api, Pontian	Pontian	Johor	Malaysia	1° 30' 54" N	103° 22' 39" E
27W	Rimba Terjun	Rimba Terjun	Pontian	Johor	Malaysia	1° 26' 51" N	103° 24' 18" E

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Table 3.

	Site	Township Subdistrict Mukim	District	Region Province State	Country	Latitude	Longitude
Zone 1: Northern Thai-Malay Peninsula							
01E	**Bang Tabun Rm.**	**Bang Tabun Ok**	**Ban Laem**	**Phetchaburi**	**Thailand**	**13° 16' 7" N**	**99° 56' 6" E**
02E	**Wa Thon Rm.**	**Khlong Wan, Huai Sai**	**Mueang**	**Prachuap Khiri Khan**	**Thailand**	**11° 42' 9" N**	**99° 44' 20" E**
Zone 2: The Kra Isthmus							
03E	Bang Son Bay	Bang Son	Pathio	Chumphon	Thailand	10° 39' 54" N	99° 18' 45" E
04E	Yai Ai Rm.	Chum Kho	Pathio	Chumphon	Thailand	10° 44' 42" N	99° 23' 24" E
05E	Phanang Tak Bay	Na Cha-ang	Mueang	Chumphon	Thailand	10° 32' 33" N	99° 14' 24" E
06E	**Thung Kha-Sawi Bay**	**Wisai Nuea**	**Mueang**	**Chumphon**	**Thailand**	**10° 20' 15" N**	**99° 8' 42" E**
07E	Riu Rm.	Bang Nam Chuet	Lang Suan	Chumphon	Thailand	10° 0' 9" N	99° 8' 60" E
08E	Tako Rm.	Pak Tako	Thung Tako	Chumphon	Thailand	10° 7' 30" N	99° 8' 42" E
09E	**Bang Man Rm.**	**Na Phaya**	**Lang Suan**	**Chumphon**	**Thailand**	**9° 50' 10" N**	**99° 8' 28" E**
Zone 3: Central Thai-Malay Peninsula							
10E	Tha Chang-Phunphin Rms.	(several)	Tha Chang, Phunphin	Surat Thani	Thailand	9° 15' 18" N	99° 13' 12" E
11E	Tapi Rm.	(several)	Mueang, Kanchanadit	Surat Thani	Thailand	9° 11' 24" N	99° 22' 3" E
12E	**Tha Phae Rm.**	**Pak Phun**	**Mueang**	**Nakhon Si Thammarat**	**Thailand**	**8° 33' 49" N**	**100° 0' 9" E**
13E	Pak Phanang Bay	Bang Chak, Khlong Noi	Mueang, Pak Phanang	Nakhon Si Thammarat	Thailand	8° 24' 27" N	100° 5' 15" E
14E	**Lam Pam Rm.**	**Lam Pam**	**Mueang**	**Phatthalung**	**Thailand**	**7° 37' 12" N**	**100° 8' 55" E**
Zone 4: The Kala Isthmus							
15E	**Songkhla Lagoon**	**Rattaphum**	**Khuan Niang**	**Songkhla**	**Thailand**	**7° 12' 22" N**	**100° 23' 6" E**
16E		Nam Noi	Hat Yai	Songkhla	Thailand	7° 7' 57" N	100° 30' 27" E
17E	Na Thap Rm.	Na Thap	Chana	Songkhla	Thailand	7° 0' 36" N	100° 44' 6" E
18E	Pattani Rm.	Rusamilae	Mueang	Pattani	Thailand	6° 52' 12" N	101° 12' 54" E
19E	Mai Kaen Rm.	Mai Kaen, Sai Thong	Mai Kaen	Pattani	Thailand	6° 37' 39" N	101° 40' 57" E
20E	Thepa Rm.	Thepha, Pak Bang	Thepha	Songkhla	Thailand	6° 51' 54" N	100° 58' 3" E
Zone 5: Southern Thai-Malay Peninsula							
21E	Penor Rm.	Penor	Kuantan	Pahang	Malaysia	3° 38' 33" N	103° 21' 54" E
22E	**Rompin Rm.**	**Kuala Rompin**	**Rompin**	**Pahang**	**Malaysia**	**2° 51' 18" N**	**103° 27' 13" E**
23E	**Endau Rm.**	**Endau, Padang Endau**	**Rompin, Mersing**	**Pahang, Johor**	**Malaysia**	**2° 39' 9" N**	**103° 36' 45" E**
24E	**Mersing Rm.**	**Jemaluang**	**Mersing**	**Johor**	**Malaysia**	**2° 25' 25" N**	**103° 50' 46" E**
25E	Tenggaroh	Tenggaroh	Mersing	Johor	Malaysia	2° 10' 57" N	103° 58' 12" E
26E 27E	Mahkota Bay	Sedili Besar	Kota Tinggi	Johor	Malaysia	1° 52' 12" N	104° 6' 27" E

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Supplementary Materials for

Examining Trade Routes through the Thai-Malay Peninsula: A Simulation Analysis

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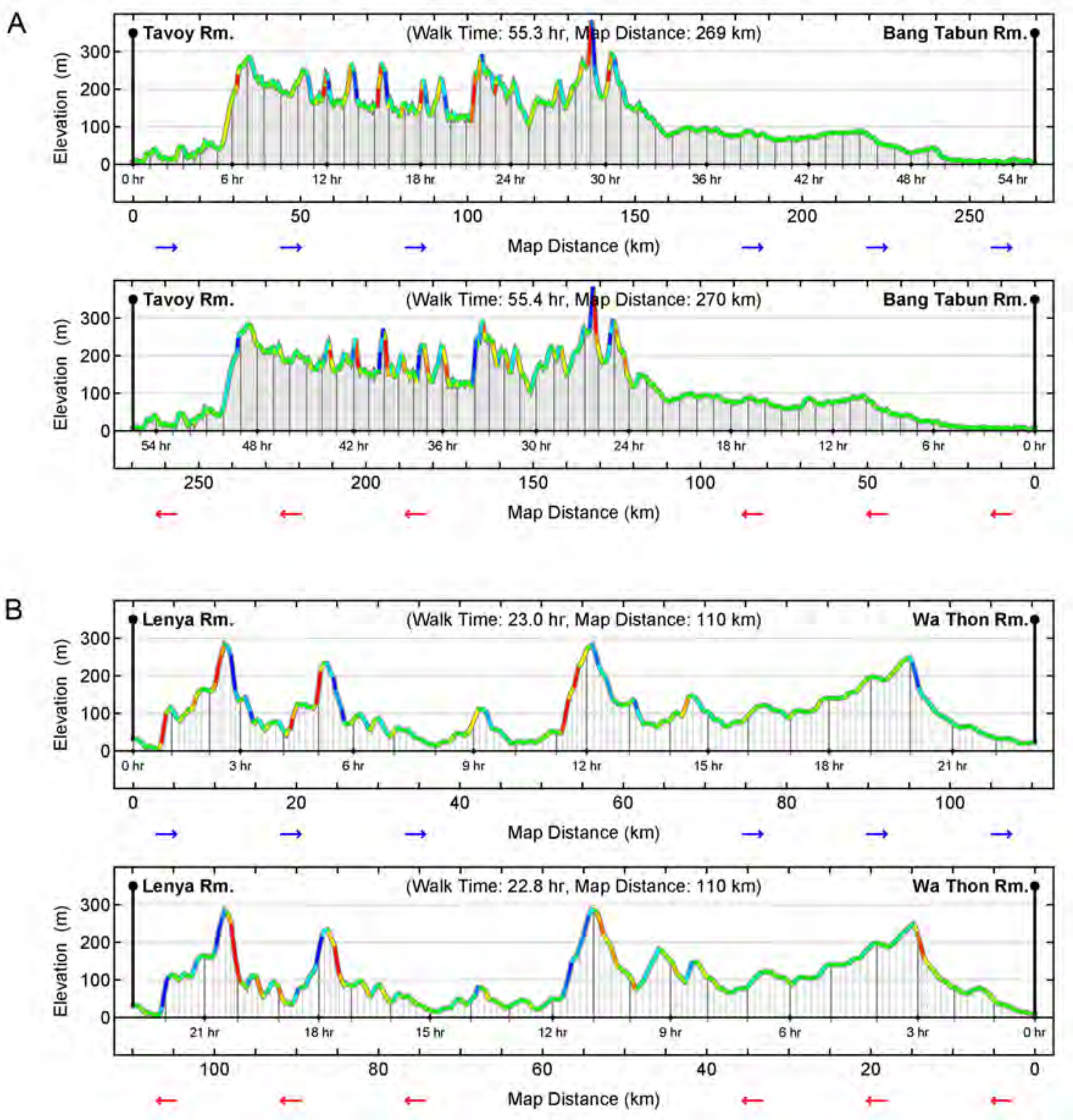

Figure S1. Elevation profiles of simulated transpeninsula routes across the northern Thai-Malay Peninsula (Zone 1) between the mouth of the Tavoy River (01W) and the mouth of the Bang Tabun River (01E) (A) and between the mouth of the Lenya River (02W) and the mouth of the Wa Thon River (02E) (B). The western coastline (the Andaman Sea and the Malacca Strait) is on the left of each graph and the eastern coastline (the Gulf of Thailand and the South China Sea) is on the right. The color of each line segment indicates its slope: reddish colors for positive, bluish colors for negative, and greenish colors for flat (or nearly flat) slopes.

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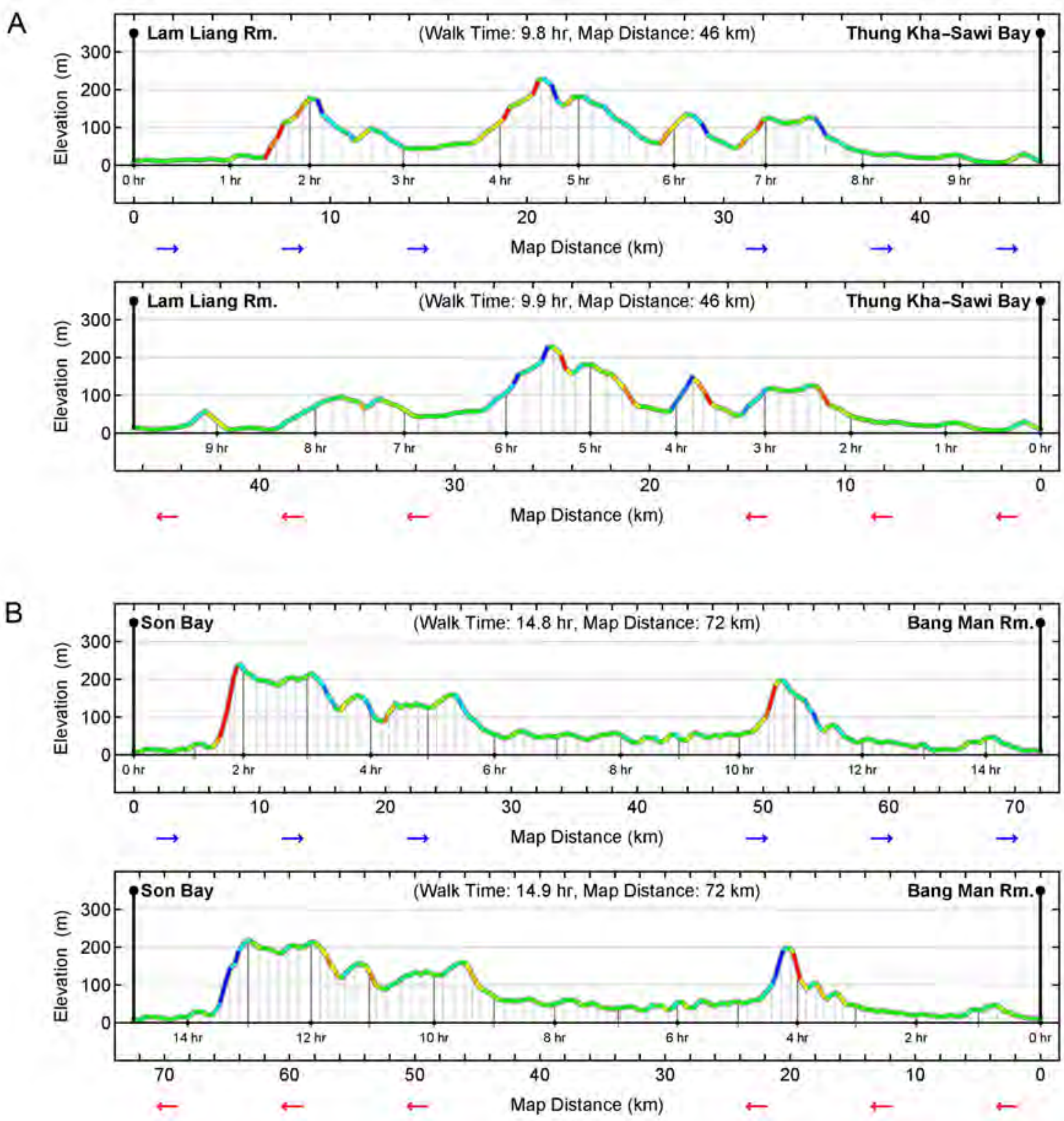

Figure S2. Elevation profiles of simulated transpeninsula routes across the Kra Isthmus (Zone 2) between the mouth of the Lam Liang River (06W) and the Thung Kha-Sawi Bay (06E) (A) and between the Son Bay (09W) and the mouth of the Bang Man River (09E) (B).

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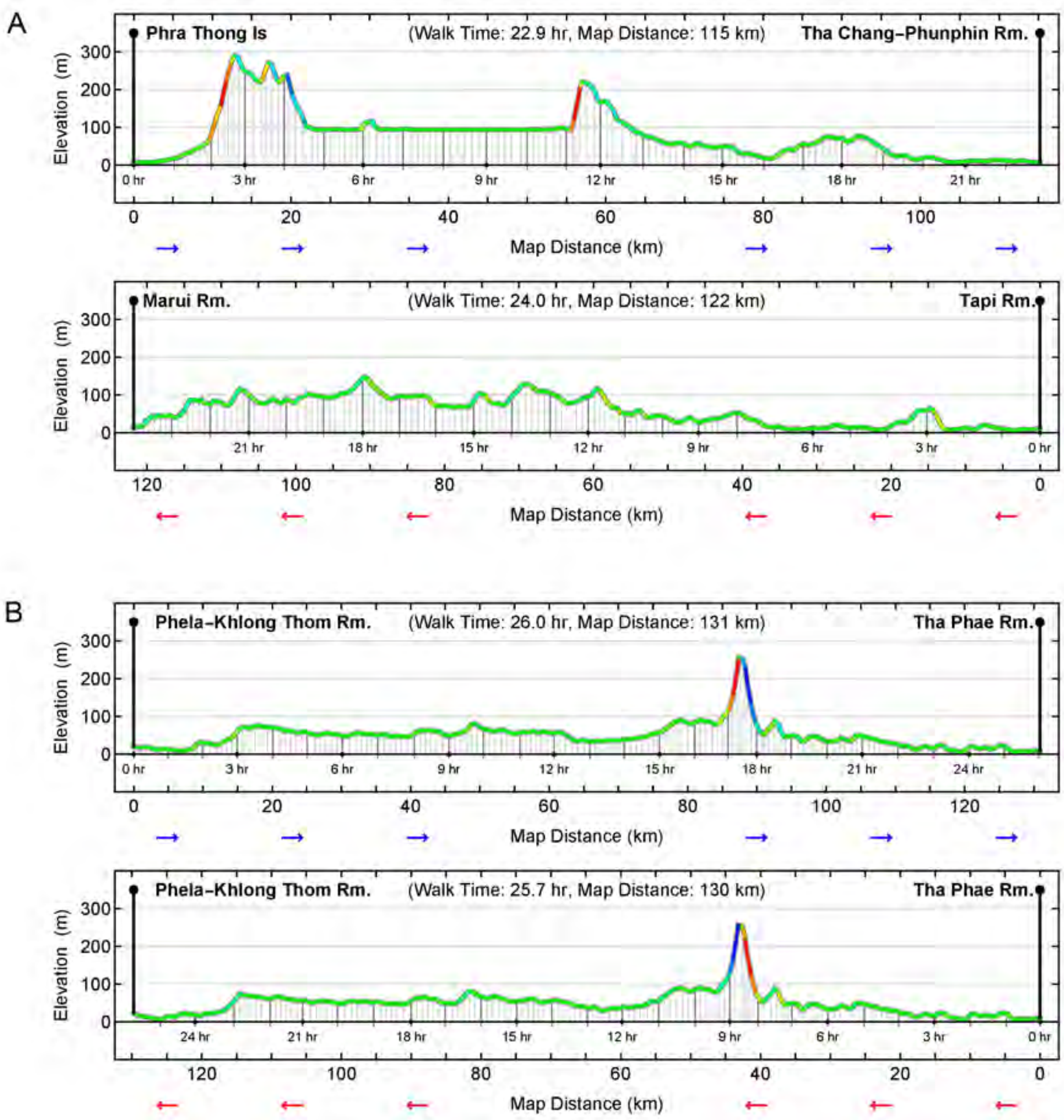

Figure S3. Elevation profiles of simulated transpeninsula routes across the central Thai-Malay Peninsula (Zone 3) from the Phra Thong Island (10W) to the mouth of the Tha Chang-Phunphin River (10E) and from the mouth of the Tapi River (11E) to the mouth of the Marui River (11W) (A) and between the mouth of the Phela-Khlong Thom River (12W) and the mouth of the Tha Phae River (12E) (B). The flat terrain in A between the Phra Thong Island and the mouth of the Tha Chang-Phunphin River is the Ratchaprapha Reservoir, an artificial water body in Surat Thani, Thailand.

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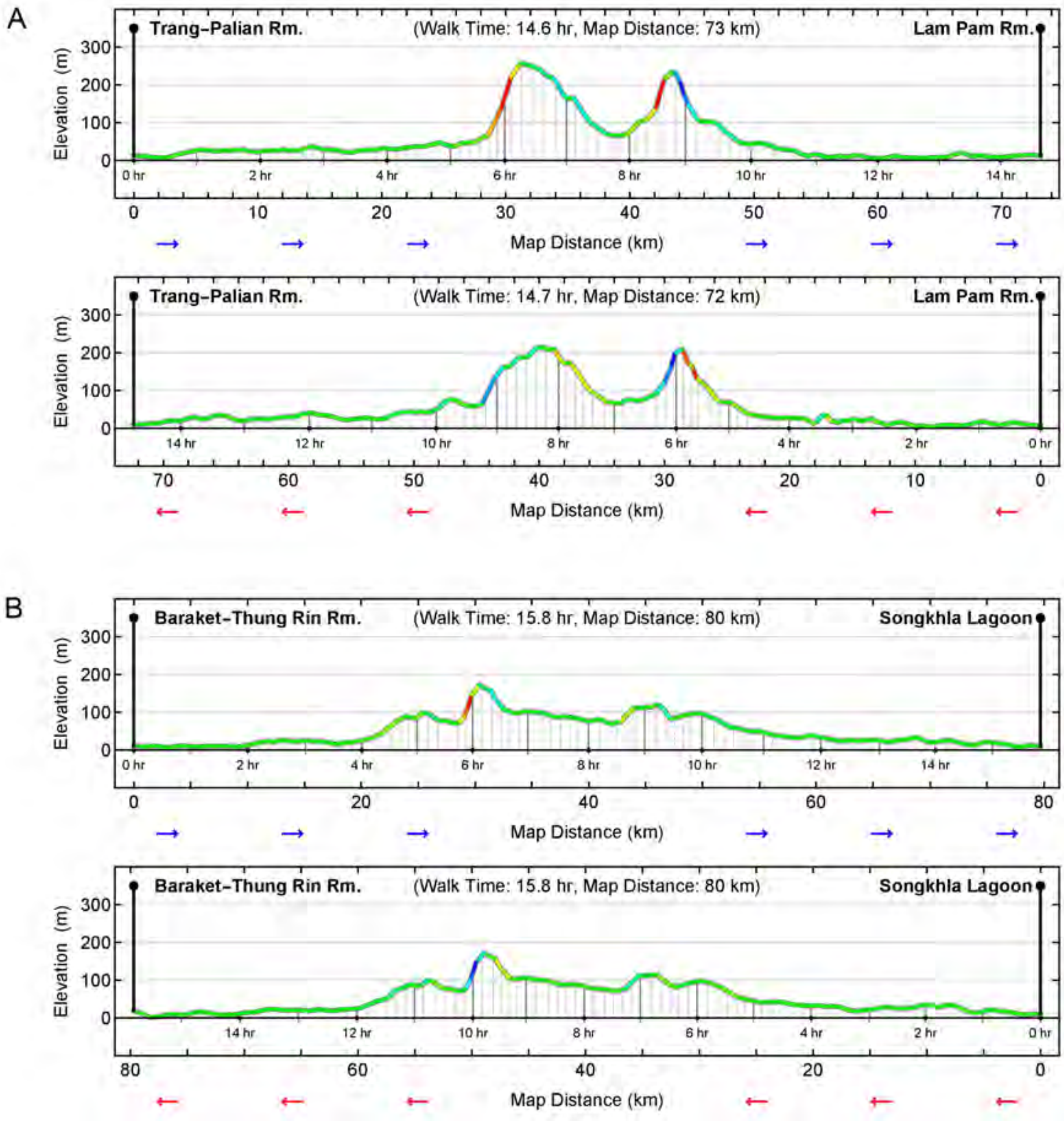

Figure S4. Elevation profiles of simulated transpeninsula routes between the mouth of the Trang-Palian River (14W) and the mouth of the Lam Pam River (14E) (A) across the central Thai-Malay Peninsula (Zone 3) and between the mouth of the Baraket-Thung Rin River (15W) and the Songkhla Lagoon (15E) (B) across the Kalah Isthmus (Zone 4).

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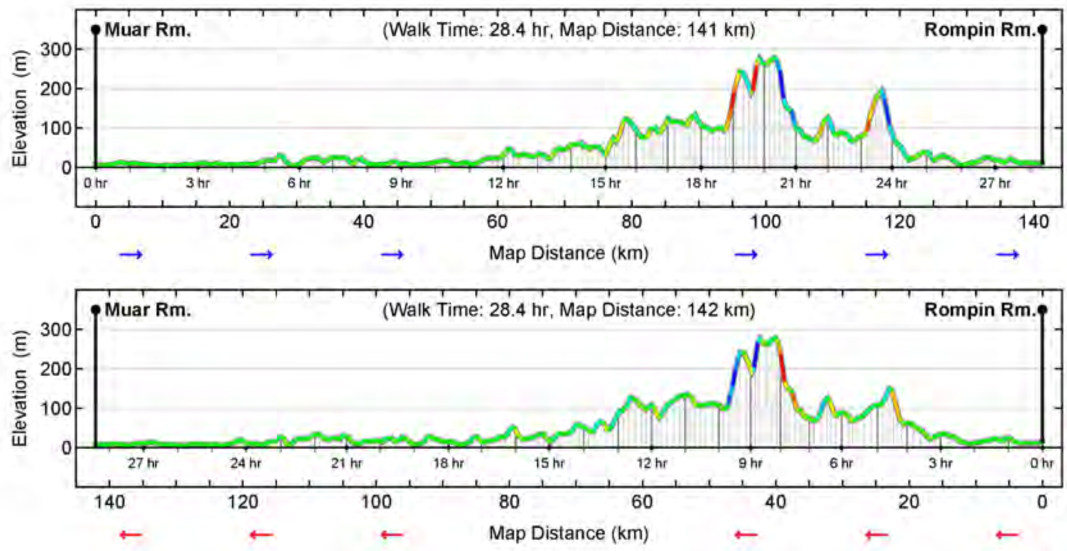

Figure S5. Elevation profiles of simulated transpeninsula routes across the southern Thai-Malay Peninsula (Zone 5) between the mouth of the Muar River (22W) and the Rompin River (22E).